ROLE OF THE INPUT AND THE FUNDAMENTAL PROCESSING CAPABILITIES OF BRAIN IN CEREBRAL HEMISPHERE ASYMMETRY

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY

by
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to the
DEPARTMENT OF HUMANITIES AND SOCIAL SCIENCES
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JULY, 1993

CERTIFICATE

It is certified that the work contained in this thesis entitled "Role of the Input and the Fundamental Processing Capabilities of Brain in Cerebral Hemisphere Asymmetry" by Dinesh P. Parihar, has been carried out under my supervision and that the work has not been submitted elsewhere for a degree.

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Thesis Title : Role of the Input and the Fundamental Processing Capabilities of Brain in Cerebral Hemisphere Asymmetry.

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Month and Year of Thesis Submission : July 1993

A great deal of research in recent years has illustrated qualitative information-processing differences between the left and right hemispheres of the human brain. Left hemisphere is shown to be specialized for verbal, analytical, and temporal-sequential processing of information whereas right hemisphere is shown to be specialized for visuo-spatial and holistic processing. Much less research has been designed to study the manner in which the two hemispheres interact in the intact brain in order to produce integrated behavioral response. With this in mind, the present work is an attempt to develop a more parsimonious model of hemispheric asymmetry: (i) to understand the nature of the phenomenon, and (ii) to evaluate and integrate the findings of existing experiments.

The present work has the following broad objectives:

(i) To evaluate and integrate the various models of hemispheric lateralization into an unifying model; to discern similarities and differences in these models; to provide missing conceptual links, if any.

(ii) To carry out initial testing of the proposed model.

(iii)To reinterpret certain experimental results in a more parsimonious way in light of the proposed model.

(iv) To highlight the importance of micro-analysis of input data for the precise formulation of concept of hemispheric lateralization.

To meet the above objectives, a thorough and critical evaluation of existing models and techniques were carried out. The aim of review was to show the strengths and weaknesses of various models and techniques. The models which were reviewed are (i) hemisphere as verbal/visuo-spatial processors, (ii) hemisphere as analytic-serial/holistic-parallel processors, and (iii) computational hemispheres. It was noted that currently two computational models of hemispheric asymmetry are generating a lot of empirical work i.e. Sergent's spatial frequency model and Kosslyn's category/coordinate model. On scrutiny, it was found that Sergent's model has emphasized the role of the input information for understanding the hemisphere lateralization; whereas Kosslyn model has stressed the brain processes as a fundamental determinant. Still, none of the models can account for entire set of data generated through empirical research over the years.

In the model proposed in the present thesis, two kinds of processors are postulated: (a) "Generalized Processor", and (b) "Specialized Processors". Moreover, it is demonstrated in the thesis that at low-level tasks, generalized processor is pressed

into operation. Conversely, at high level tasks specialized processors of left hemisphere are used, if relatively programmed and attentional processing is required (called Rule Based processing). On the other hand, right hemisphere processors are used in condition of relatively non-programmed and non-attentional processing (called Random Processing). Moreover, the proposed model has some additional mechanisms which states that under condition of data limitation a low-level task would be processed by specialized processors and under conditions of over practice a high-level task would be processed by generalized processor.

The model proposed, makes some specific predictions such as: (i) at low-level task there would be no lateralized interference in the tapping of both hands, but only generalized interference in concurrent-task paradigm; (ii) at high-level task, as the complexity of rule increases in order to process the task, there would be more disruption in right hand tapping than the left hand tapping; (iii) practice of high-level task would show diminishing lateralized interference; and (iv) data-limitation of low-level task would show lateralized interference in unimanual tapping. These predictions of the model were tested in a series of four experiments.

The present investigation employed the concurrent task-paradigm in which subjects were required to do one motor and one cognitive task, simultaneously. In Experiment 1A, a tapping task with varying difficulty of the tapping sequence was used. It was hypothesized that program involved in carrying out the tapping sequence will serve as a concurrent cognitive task. In

Experiments 1B and 2A, verbal-articulation was used as concurrent task whereas in Experiment 2B, it was comprehension of verbal material.

Different groups of ten males and ten females in age-group of 18 to 30 years participated in the experiments. All the subjects were self-declared right handers. The data were collected using a personal computer which also did the preliminary analysis of data at the time of collection, itself. Preliminary analyzed data were subjected to 2 (Sex: Male, Female) x 2 (Hand: right, left) x 4 (Practice Trials) x 5 or 2 (Task-condition) ANOVA with repeated measures on last three factors.

The analyses of data revealed that (i) postulation of generalized processor seems to be a good working hypothesis; in experiments 1A and 2A, i.e,at low-level task only generalized interference in tapping was observed, even for the tasks which in earliar experiments had been shown to produce lateralized effects; (ii) at high-level task, under condition of complex rule as in experiment 1A, a lateralized interference was observed in the tapping task; (iii) the effect of practice trials did support the hypothesis but not in a striking manner; and (iv) sex differences turned out to be nonsignificant in all the experiments.

Based on results, it was concluded that left hemisphere specialized processors carry out their processing at high-level tasks, when rule based Processing is required. Conversely, right hemisphere specialized processors handle high-level task when random processing is required. The generalized processor works at low-level task under normal input conditions.

These results have implication for future research. More research is needed to verify or falsify the different predictions of the model by using different techniques and different sets of input conditions. Further, results also suggest the need for an indepth analysis of tasks into their subcomponents so that possibility of alternative explanation could be ruled out and future research is guided in right direction in a more fruitful way.

TO

My Extraordinary, ordinary Friend

SAMUDRAVIJAY

TABLE OF CONTENTS

PREFACE

The left and right cerebral hemispheres of humans differ in their functional organization, despite their apparent morphological similarity. While hemispheric asymmetry has been known to exist for centuries, the renewed interest in the field during last 25 years can be traced to the pioneering work with the commissurotomy patients by Roger Sperry and his colleagues. The vivid demonstration of hemispheric asymmetry provided by Sperry, captured the imagination of both scientists and the lay public. As a result, we have witnessed a tremendous amount of work in this area. The end product of this hectic scientific enterprise is a basic scientific principle of human biology, namely, that cerebral hemispheres are remarkably asymmetrical in their functional organization. But researchers are yet to formulate a precise and unifying model of hemispheric lateralization which account for whole range of data generated over the years and whose prediction can be operationally tested.

The present research focuses on the complexities of hemispheric lateralization. It has attempted to report, evaluate and integrate various models of hemispheric asymmetry into an unifying model which would be: (i) empirically feasible and (ii) which accounts for more data than any other model of the phenomenon. Moreover, the research also attempts to experimentally test the predictions of the model as well as reinterpret certain experiments in light of postulates of the current model.

The thesis has been organized into three chapters. Chapter I addresses itself to outlining the various models of hemispheric asymmetry. It also discusses the prevalent techniques used to study the hemispheric specialization. The chapter is divided into four major sections.

The first section deals with the various models of hemispheric asymmetry. It also discusses problems associated with the models. It attempts to discern possible similarities and differences in existing models so that a more parsimonious model could be worked out.

The second section discusses the different techniques which are used to study the hemispheric asymmetry. Experimental techniques of visual-half field presentation, dichotic listening and concurrent task paradigm are discussed in detail as these techniques are frequently used to study the phenomenon. However, the emphasis of the second section is on concurrent task-paradigm as this technique is used in the present investigation. The concurrent task paradigm is found to be more flexible and comprehensive than the other experimental techniques on account of its ability to accommodate wide variety of stimulus condition for study of hemispheric lateralization. The third section consists of sex related differences as well as effect of practice in area of hemispheric lateralization. Sex is included as an independent variable in the research because findings are equivocal about its relation to hemispheric asymmetry and precise nature of these differences are not clear. The variable of practice is included in the study because it is an important concept in the proposed

model.

The final section of Chapter I, embodies the proposed model. It is claimed that the proposed model is a more parsimonious model of hemispheric asymmetry than any other model on account of: (i) its internal consistency, (ii) its ability to explain more data, and (ii) its ability to synthesize current models and propose some new mechanisms, hitherto unproposed, to clarify and sharpen the conception of hemispheric lateralization. Rationale and hypotheses of proposed experiments are also presented in the fourth section.

Chapter II contains all the four experiments. These experiments are reported in terms of specific hypothesis, methodology, results and discussion.

Chapter III includes general discussion of all the experiments, summary and conclusions. It also discusses implication of the present research and its limitation.

I would like to thank a number of people who have directly or indirectly contributed to my research in different ways. The name that comes first to my mind is that of my thesis supervisor, Dr. N.K. Sharma. He has always been a source of inspiration. He has provided me with high degree of freedom to work, at the same time, he has given his valuable and sought after guidance whenever required. I am deeply indebted to him for his support and cooperation.

My thanks are due to Drs. L. Krishnan, M.A. Ansari, A.K. Sinha, and S. Omprakash who enriched my knowledge through course work. I would also like to express my gratitude to Dr. B.N.

Patnaik, and Dr. Bijoy Boruah for their insightful comments and encouragement.

I would be failing in my duty if I do not acknowledge Yakub Ali for developing the computer program for collection of data, Chanchal Kumar for his help in developing the computer program for analysis of data, Shekhar Shukla, K.N. Tripathi, and Nachiketa Tripathi for preparation of figures as well as Manmohan Pandey for his friendly help.

I would also like to express my thanks to my batch mates Seema and Arti for their help and support, Nagarjun and Nissar for their comments, and Sarbjit Kaur as well as Govind Swaroop Pathak for their help and cooperation.

I would like to express my gratitude to all the subjects who readily participated in the experiments.

Finally, I would like to thank Rajendra Nigam and D.K. Srivastava for their meticulous typing.

July, 1993 U.I

LISTS OF ABBREVIATIONS

ANOVA	=	Analysis of Variance
A	=	Sex
B	=	Hand
C	=	Practice Trials
D	=	Task Conditions
GP	=	Generalized Processor
SPs	=	Specialized Processors
RH	=	Right Cerebral Hemispheres
LH	=	Left Cerebral Hemisphere
P	=	Probability
RVF	=	Right Visual Field
LVF	=	Left Visual Field
LEA	=	Left Ear Advantage
REA	=	Right Ear Advantage
PET	=	Position Emission Tomography
CAT	=	Computer Tomography
rCBF	=	Regional Cerebral Blood Flow
EEG	=	Electro-Encephalogram
ERPs	=	Event Related Potentials

LIST OF TABLES

List of Figures

CHAPTER 1

INTRODUCTION

Contents

AN OVERVIEW

The fundamental aim of the present chapter is to clarify the nature of hemispheric asymmetry by evaluating the existing models and techniques in the light of reported findings. It also aims at proposing a new model of hemispheric lateralization to sharpen the conception of hemispheric asymmetry and to account for larger empirical data in a more consistent way. The chapter has been organized into two parts. The first part is a detailed account of the state-of-the-art of the problem. It has been further divided into four sections. The first section is an attempt to outline the nature of hemispheric asymmetry by presenting dominant existing models. The second section attempts to present different techniques used to study hemispheric lateralization. The third section contains sex related differences in relation to hemispheric asymmetry. The fourth section deals with studies of effect of practice on lateralization. The second part of the present chapter gives an outline of the research proposal including the rationale for the proposed model and experiments.

THE BACKGROUND

The nature of hemispheric laterlization:

The left and right cerebral hemispheres of humans differ in their functional organization. While hemispheric asymmetries have been know to exist for centuries, the renewed interest in this field during the last 25 years can be traced to the pioneering

work with commissurotomy patients reported by Roger Sperry, Michal Gazzaniga, and his colleagues (e.g. Gazzaniga, 1985; Sperry, Gazzaniga, and Bogen, 1969) as well as the influential book of Leneberg (1967). The vivid demonstrations of hemispheric asymmetry provided by Sperry et. al. (1969) captured the imagination of both scientists and lay public. As a result, we have witnessed a tremendous amount of work in this area: a nearly geometrical increase in the number of articles dealing with aspects of hemispheric asymmetry (Hellige, 1990). The end product of this hectic scientific enterprise is a basic scientific principle of human biology, namely, that cerebral hemispheres are remarkably asymmetrical in their functional organization. Despite this, researchers have yet to formulate the precise nature of this phenomenon. In addition, many empirical findings have been shown to be unstable and are difficult to replicate (see Beaumont, 1982). A critical evaluation of existing models of hemispheric asymmetry which have generated a lot of empirical research are presented below.

The verbal/visuo-spatial Hemispheres.

In the early phase of research in the area of lateralization, on the basis of brain damage studies, it was hypothesized that the left hemisphere is specialized for linguistic activity (Broca, 1865; Dax, 1865; Wernicke, 1879) and the right hemisphere is specialized for visuo-spatial activity (Hughlings Jackson, 1876). The basis for such a claim was an asymmetrical representation of language in the left hemisphere of aphasic patients. Early researchers held the view that all language related activity

resides in the left hemisphere (LH) that is, they proposed what Allen (1983) called the 'unilateral specialization model'. The principle of such a viewpoint was that only one hemisphere performs a given psychological process.

This view was strengthened in the present century by Kimura's (1961) demonstration that language stimuli presented to both ears simultaneously, were reported more accurately from the right ear than the left ear. Thus, the first fundamental dichotency suggested was between verbal - major (left hemisphere) and nonverbal-minor (right hemisphere). Inherent in the above proposition is a value conception, that is - LH as major hemisphere and RH as minor hemisphere. Such value conception was attached to LH and RH because: (i) initially many psychological functions were attributed to LH whereas RH languished in relative impoverishment (Allen, 1983), and (ii) it was held that human being generally process and store information in linguistic form (Hellige, 1990).

A number of modern researchers have claimed unilateral specialization for a variety of linguistic functions. In an extremely influential work, Leneberg (1967), concluded that most language functions, after an early state of equipotentiality become completely lateralized to the LH (see St. James - Roberts, 1981, for a critical review). Other theorists willing to make unilateral representation of language in LH are De Renzi, (1978), Gazzaniga and LeDoux (1978), and Kinsbourne (1978). Still, other theorists (Satz, 1979; Rasmeussen & Milner, 1977) argue for such thesis based on individual difference variable of handedness.

In addition, a number of theorists have embraced weaker forms of unilateral language hypotheses, typically limiting their claims to a particular, well specified subcomponent of language rather than language as whole. Nebes (1974), reviewing the human commissurotomy data, rejected conclusion that LH seems solely in control of musculature necessary for speech production. There have also been claims for unilateral specialization for perception and comprehension of language. Molfese (1980), extending earlier work of Studdert-Kennedey and Shankweiler (1967), has argued that a number of specific components of speech signals (e.g. voice on set time) may be unilaterally processed. Other researchers suggest such claim for verbal coding processes (Seamon, 1974; Seamon & Gazzaniga, 1974), category matching (Urcuioli, Klein and Day, 1981), and recognition of consonant-vowel syllables (Springer & Deutsch, 1977). In an excellent review of RH linguistic ability, Searleman (1977) noted that the case for unilateral specialization of linguistic functions seems much more frequently made for the production aspects of language than for the comprehension aspects.

RH specialization for visuo-spatial functions are usually made. It has been noted, however, that whereas a fair number of theorists posit unilateral specialization for language functions, relatively few seem willing to do the same for visuo-spatial functions (Moscovitch, 1973). For example, De Renzi (1978) concluded that whereas some aspects of spatial functioning may be unilaterally specialized, others are bilateral, and Nebes (1974) seemed mostly inclined toward a relative rather than absolute

difference between hemispheres for visuo-spatial functioning. Gazzaniga and LeDoux (1978) made a strong statement against unilateral thesis for visuo-spatial functions.

One particular aspect of visuo-spatial processing for which unilateral thesis is often claimed is face recognition. This claim, however, has proven difficult to substantiate due to a number of factors among which are: (a) the confounding in many experimental paradigms of face recognition and affective processes, (b) failure to replicate some of the critical findings (Carey & Diamond, 1977; Yin, 1970) on which claim rests, and (c) the possibility that there may be more than one type of face recognition process. (For discussion of this issue see: Benton, 1980; Bradshaw & Nettleton, 1981; Sergent and Bindra, 1981.)

One of the earliest claims for unilateral specialization of motor functions was made by Liepmann (1908), who hypothesized that LH might be solely in control of a "purposive motor sequence". Damage to LH leads to various disorders of learned movements, or apraxias. Although widely discussed at that time, Liepmann's hypothesis received relatively little attention in the intervening years, resurfacing only recently (Geschwind, 1975; Heilman, 1979; Kimura & Archibald, 1979; Nottebohm, 1979). Lomas (1980), and Lomas & Kimura (1976) advanced a similar view but argued that LH was unilaterally specialized only for motor functions requiring rapid-repositioning of musculature.

In general, research supports the premise that LH is dominant for a variety of language tasks, such as production (Hicks, 1975; Kinsbourne & Hiscock, 1983 a); perception (Kimura, 1961) and

others, whereas RH is dominant for many nonverbal/spatial tasks, such as the recognition of human faces (Berent, 1977); cartoon drawings of faces (Levy & Brydon, 1979); and schematic drawing of faces (Bradshaw & Sherlock, 1982; Sergent, 1982) as well as other visuo-spatial functions.

But soon data began to emerge which led to rejection of stimulus based dichotomy (for review, see Allen, 1983; Bryden 1982; Bradshaw & Nettelton, 1983). The position of early researchers was that all language functions reside in LH, has undergone an increasing erosion as evidence for RH involvement in various aspects of language has steadily increased (Searleman, 1977). For example, RH contribution to various aspects of language functions reported were; damage limited to RH may result in impaired prosody (Ross, 1981) and in difficulties in processing complex linguistic entities and in utilizing the surrounding context in the comprehension of linguistic messages (Wapner, Haneby & Gardner, 1981). Moreover, studies showed relatively small ear differences with dichotic listing techniques (Shanks & Ryan, 1976; Johnson et. al., 1977); ability of brain damaged population to perform speech perception tasks with some degree of competence even after LH is damaged (Zaidel, 1983; 1977); involvement of RH in syntactic processing (Eisenson, 1962; Hier & Kaplan, 1981). Similarly, anatomical and clinical evidence has been reported suggesting both hemispheres are involved in face recognition (Damasio, Damasio, & Van Hocsen, 1982; Meadows, 1974). Moreover, with regard to mental imagery, there is little evidence for a RH advantage (Erlichman & Bareft, 1983), and some studies

even suggest an LH advantage for image generation process (Farah, 1986).

When it become clear that the verbal/nonverbal nature of stimulus was not the fundamental factor for hemispheric specialization, it was suggested that the critical characteristic was whether or not the stimuli were processed in verbal manner (Hellige, 1990). While it was clearly a step in the right direction to emphasize processing differences rather then stimulus differences, this view was also rejected (i) because any kind of verbal/non verbal dichotomy was found unsatisfactory, and (ii) it was demonstrated that both hemispheres did have competence for one or other aspects of verbal/visuo-spatial functions.

The Analytic/Holistic Hemispheres:

The foregoing review suggests certain important features of hemispheric asymmetry. These are: (i) both hemispheres have some degree of competence in processing of any kind of information, regardless of the nature of task. However, processing competence might not be equal for different kinds of task; (ii) labelling a task as verbal or visuo-spatial is over-simplification. Every task is made up of specific subcomponents, e.g. language consists of syntactic, semantic, prosodic and pragmatic components. These subcomponent may be differentially distributed over LH and RH, and (iii) future studies must be carried out after detailed analysis of task in which a clear description of the necessary steps or operations that must be performed in order to process the task should be clearly stated, and precise hypotheses regarding demands of these operations on the cognitive system should also be stated.

When it become clear that verbal/visuo spatial dimension of stimulus is not sufficient to explain the experimental findings about the different aspects of hemispheric lateralization, a more refined and comprehensive dichotomy was suggested, that is - two hemispheres differ in terms of analytic/holistic mode of processing. According to this model, LH is specialized for verbal, analytic, and temporal-sequential processing of information, whereas RH is specialized for visuo-spatial and holistic parallel processing of information (Bradshaw & Nettleton, 1981; Witelson, 1985). In this model, LH is supposed to process discrete details of information one after the other, temporally. Conversely, RH is supposed to process several details of information simultaneously, creates a new whole out of them and arranges them spatially. Thus, Cohen (1973), in an important and frequently cited article advanced the hypothesis that hemispheres may be differentially specialized. Cohen's suggestion was that the LH processes information in a serial fashion, i.e. processing time increases with the number of elements to be processed, whereas RH operates in a parallel fashion i.e. processing time is independent of the number of elements to be processed. Similarly, Bogen (1969), has argued that hemisphere asymmetry results from the two modes of thought, propositional and appositional. The propositional way of processing refers to the fact that hemispheres use words, that is, they are capable of formulating propositions and carrying out logical deduction on those propositions. On the other hand, appositional mode of processing refers to intuitive creation of whole or gestalt out of input

material. The propositional mode is associated with LH while the appositional mode is associated with RH.

Several visual search studies have been carried out to test the above model. A LH-RVF superiority in accuracy of identification and speed of response is reported with serial demand tasks and a RH-LVF superiority in performance with tasks that demand a parallel processing (Cohen, 1973; Magaro & Chamrad, 1983). However, other studies failed to find such distinction (Polich, 1984) or produced equivocal results.

The analytic/holistic dichotomy is immediately called into question. The primary problem is that the analytic/holistic distinction has not been operationalized sufficiently to make clear empirical test possible (Hellige, 1990). Researchers often disagree about whether a task requires analytic or holistic processing. Given the variety of tasks that evidence hemisphere asymmetries, it may be impossible to collapse the results into any single well defined dichotomy. Moreover, labelling a task or a hemispheric way of processing as verbal/nonverbal or analytic/holistic reveals little about the cognitive components that are engaged in the processing. It seems oversimplified to assume that a complex task, like high level visual shape processing, will be better handled by RH because this hemisphere may be specialized to deal with visuo-spatial information. Similarly, it also seems too simple to assume that complex tasks such as spelling, reading or writing, for example, will be better carried out by LH because this hemisphere is specialized to process verbal material (Koening 1990).

Another problem with aforesaid models are their resistance to contrary evidence, thus challenging Popper's (1963) criterion of falsifaibility of models. For example, finding that LH aphasics were as impaired as RH aphasics in recognizing faces, Benton (1980) concluded that face recognition was a "language dependent performance" without considering in his interpretation that the LH might possess visuo-spatial competence. Similarly, Segalowitz, Bebout, and Lederman (1979) found a RVF-LH advantage in the identification of visually presented chords to musicians. They suggested that this resulted from an analytic mode of processing without any indication in their data of such an analytical operation (Sergent 1983).

To further complicate matters, current research indicates that both hemispheres have some analytic and holistic processing capabilities (Cohen, 1975; Sergent, 1982a; 1982b; Sergent & Bindra, 1981). Sergent's research has demonstrated that both cerebral hemispheres can process verbal and visuo-spatial information and both can process that information analytically as well as holistic ally. The major difference in their functioning appears to be the amount of sensorimotor resolution (details) required for the processing of the stimulus information presented. For example, if the information is degraded (of poor quality), has relatively few subcomponets or parts, and/or has low spatial frequency, the RH shows a processing advantage. Conversely, LH advantage is obtained for high resolution information, having many components and consisting of high spatial frequency.

Therefore, it seems logical to deduce that analytic and holistic mode of processing may not be separated as exclusive functions of LH and RH respectively. Instead, results do suggest a continuum at which both hemispheres have analytic and holistic capabilities, albeit asymmetrically. Moreover, as Sergent (1983) has noted: "On both logical and empirical grounds, a temporal-analytic/spatial-holistic dichotency appears to be unlikely. Temporal and spatial dimensions are such basic properties of any experience that it is hardly conceivable that each hemisphere would be bereft of one of them. Music, for instance, whose RH-mediation is well documented (e.g. Critchley & Herson, 1977), is considered by some as paradigm par excellence of temporality (Jankelivitch; 1977). In addition, one cannot ignore the spatial dimension underlying LH-mediated production of writing (Hacaen & Albert, 1978)...."

It follows from the above comment that both hemispheres have analytic as well as holistic competence. These considerations led Bradshaw and Nettleton (1981) to suggest that analytic/holistic dichotency is not a matter of nature but of degree; not a qualitative but a quantitative difference.

Inherent difficulties with dichotomous models of hemispheric asymmetry have led to formulation of the computational approach to hemispheric lateralization. This approach is based on the premise that hemispheric asymmetry can vary from subsystem to subsystem within a given task. Therefore, the best way to know about such asymmetry is to know the nature of relevant computations on a subsystem and how the computations of different subsystems are

related to processing asymmetry of a particular task.

The Computational Hemispheres:

Even relatively simple tasks require the coordination of a number of information processing subsystem or modules (e.g. Anderson, 1985; Stillings et. al. 1987). The hemisphere that is dominant for one subsystem may not be dominant for all other subsystems involved in that task (e.g. Allen, 1983). For example, in a memory scanning task with letters I (Hellige, 1980) a LVF-RH advantage for encoding a visually presented probe letter was reported, but a RVF-LH advantage was found for memory comparison. The fact that hemispheric asymmetry can vary from subsystem to subsystem within a task suggests that such asymmetry is best studied in terms of relevant subsystems. This proposition is the basis of computational approach to hemispheric asymmetry.

Further, the growing interest and recent developments in cognitive neuroscience, for example, information accumulation regarding the neuroanatomy and neurophysiology of vision (Arbib & Hanson, 1987; Mishkin, Ungerleider and Macko, 1983; Van Essen, 1985) have also given impetus to the computational approach. Indeed, theories have been developed in which psychological processes are described in terms of the operations of functional brain components, and brain function is conceptualized in terms of computations. This approach offers precise description of how information is processed in the brain and provides substantial benefits for understanding high level cognitive mechanisms.

Basic to computation approach is the assumption that any kind of task (e.g. verbal, visuo-spatial etc.) is made up of number of

subcomponents and different subcomponents of task are processed by different subprocessors. These subprocessors may be unilateral or bilateral. Thus, lateralization is traced at molecular level and not at molar (hemisphere) level. The notion of subprocessors is not a radical suggestion. The general notion that tasks and functions are performed by complex aggregates of smaller processing units, is one of the most prevalent features of modern psychological theory (Arbib & Caplan, 1979; Dean, 1980; and McClelland, 1979). The subprocessors are defined in terms of hemispherically relevant characteristic, that is function and anatomical location.

The formulation of hemispheric asymmetry in terms of computational approach has changed the meaning of hemispheric lateralization. For simple subprocessor, the traditional meaning will do. But for complex multi-subprocessors, hemispheric asymmetry would be an interactive and dynamic function of the relations between the subprocessors. At this point, the question about the identification of subprocessors arises. The question involves two problems (i) what a subprocessor does, and (ii) where it does (Allen, 1983). A precise analysis of the task to be processed is required to answer the first problem and the second problem could be handled by use of sophisticated brain-mapping techniques e.g. EEG, rCBF, PET etc.

Two models of hemispheric asymmetry in computational terms are generating lot of empirical work. They are (i) Sergent's spatial frequency model; and (ii) Kosslyn's coordinate/category model. The detail analysis of the quality of stimulus input has

led, Sergent (1983; 1987a, b) to formulate her model. Similarly, a systematic inquiry into the neuroanatomy and the neurophysiology of the visual system has led Kosslyn (1987; 1988) to formulate a computational theory of visual cognition.

The quality of stimulus input is important for determining hemispheric asymmetry in visual information processing. For many tasks that use visual stimuli, reducing perceptual quality by utilizing masking stimuli, blurring, and other interference with performance more when stimuli are projected to the LH than when they are projected to the RH.

Thus, the major difference in how each hemisphere will process information is dependent on the amount of sensorimotor resolution (details) required for the processing of information. On the basis of the above logic, Sergent (1983, 1987a, b) has hypothesized that, at some level of processing beyond the sensory cortex, the LH and RH are biased toward efficient use of higher and lower visual spatial frequencies, respectively. The effects of reducing stimulus perceptibility can be explained by this hypothesis if it is assumed that manipulation used to reduce perceptibility result in selective removal of higher spatial frequency information.

The advantage of the spatial frequency hypothesis over previous dichotomies is that it is, in principle, more amenable to operational definition and rigorous empirical test. Under many conditions selective removal of higher ranges of spatial frequencies impairs LH relative to RH performance, as predicted. However, there is a growing evidence that the range of spatial

frequency information required to perform an experimental task is as important as the range of spatial frequencies contained in the stimuli, with some complex interaction emerging when both things are varied (e.g. Christman, 1987, 1990; Sergent & Hellige, 1986).

Kosslyn (1987), has hypothesized that human brain computes two different kinds of spatial relation, to assign a spatial relation to a category (e.g. "out side off" or "above") whereas the other preserves location information using a metric coordinate system in which distances are specified effectively. He proposed the aforesaid hypothesis on the basis of detailed scrutiny of neuroanatomical and neurophysiological research about the spatial-relation representation.

Ungerleider and Miskkin (1982) provided evidence for the existence of two cortical visual systems in the monkey. The first system (the ventral system) runs from the primary visual cortex (OC) down to the inferior temporal lobe (area TE) and is hypothesized to deal with the processing of the shape (the "what") of the object. The second system (the dorsal system) runs from area OC to the parietal lobe (area PG) and is thought to be concerned with the analysis of the location (the "where") of an object.

Kosslyn (1987) pointed out that converging evidence can be found in human patients suffering from bilateral temporal lobe damage who have difficulties in shape identification but do not have localization problem. On the other hand, patients suffering from bilateral damage to the parieto-occipital regions shows difficulties in localizing stimuli, but not in recognition (De

Renzi, 1982).

Neurophysiological studies also provided supporting evidence. The visual areas in parietal lobe rarely include the fovea and do not strongly respond to shape, size, and color but respond to direction of motion. In contrast, visual area in the temporal lobe appears to be sensitive to shape texture, and color (Desimone, Albright, Gross & Bruce, 1984). Taken together, these observations led Kosslyn (1987) to hypothesize a set of subsystems in ventral system which encode shape, store invariant properties of objects (e.g. the relations "above", "below", "connected to", "to the left of", and so on) and a set of subsystems in the dorsal system that encode location i.e. the precise coordinates of the objects - or of parts of an object - are specified relative to a single origin. Further, Kosslyn et. al. (1988) claimed that categorical spatial relations are "language-like" because they usually correspond to word-concepts. Thus, LH is hypothesized to be better at processing categorical relations than the RH. In contrast the coordinate system is hypothesized to be more efficient in RH. This hypothesis is supported by evidence that the RH is more efficient at processing metric spatial relations (De Renzi, 1982). It is important to note, however, that each component of the model is represented in both hemispheres. Nevertheless, certain components may be more trained or more efficient in one given hemisphere.

One could argue, at this point, that categorical/coordinate distinction is nothing more than an additional dichotomy in the field of hemispheric literature. The difference, compared to

traditional dichotomies is that the actual distinction is clearly motivated by a theory of information processing and is intended to reflect how brain computes visual information (Koening, 1990). This distinction is objectively definable and questions raised by this dichotomy is very explicit, thus easy to experimental verification or falsification. In fact, Koening (1990) has claimed that RVF-LH advantage for language processing could arise because many of the language skills require the use of some kind of categorical subsystem. In other domains, such as face perception, for example, the traditional LVF-RH advantages could appear not because there is a specific system specialized for face encoding and processing in RH, but because a metric (coordinate) sub-system is often needed to process this type of stimuli. As a matter of fact, recent evidence seems to confirm that face perception is not an independent mechanism (Bruyer, 1988).

Though the model presented by Kosslyn is in its nascent form, therefore, detailed comments are not feasible. Still, it is clear from the reviewed literature that it does not account for the entire set of empirical data. For example, it is silent on role of input characteristic in relation to hemispheric asymmetry. Moreover, it concludes that categorical relations are better handled by LH from the fact that such relations are "language like". This is a case of circular reasoning because, in the first place, computational models have rejected the verbal/non-verbal dichotomy.

Techniques used in the study of Hemispheric asymmetry

A wide range of techniques have been used to study hemispheric asymmetry. They can be broadly classified as neuro-physiological, clinical, and behavioral or experimental techniques. The neuro-physiological techniques include (i) observation of anatomical asymmetry, (ii) brain-mapping by EEG, PET and rCBF, and Wada technique etc. Clinical techniques consist of (i) the lesion studies, and (ii) split brain studies. Experimental techniques refer to (i) divided visual field studies, (ii) dichotic listening studies, and (iii) the concurrent task studies. These techniques were evaluated in order to know (i) stimulus parameters associated with different techniques, (ii) technical restraints associated with these techniques, (iii) problem associated with them, and (iv) how much reliance could be placed about the validity and reliability of these technique.

Anatomical evidence: Geschwind & Levitsky (1968) reported dominant patterns of gross anatomical asymmetry in the human cerebral hemispheres. They examined the outside border of the planum temporale (a language related area on the posterior-superior temporal plans) and found that 65 of the 100 brains they examined had a larger left planum, 11 had the reversed asymmetry, and 24 had no bias. The result have since been confirmed in a number of different studies (e.g. Wada et. al 1975; Witelson & Pallie, 1973). Since planum area is part a of Wernicke's area, it has been proposed that this asymmetry may be responsible for the localization of speech in the LH. Asymmetries in the length of the sylvian fissures were assessed directly on

of extracting the invariants of instances of a category (Harnard, 1981) is not involved in such cases, and only one instance of unique stimuli is subjected to familiarization. This suggests that processes are still performed on neural "analogues" of the physical characteristic of stimulus. However, one effect of familiarization is to increase the prominence of the relevant physical dimensions of a stimulus (Pick, 1965). Shepp (1978) has shown that there are additional progressions in the perceived stimulus structure that emerges in course of perceptual learning . If the relevant perceptual features of a stimulus become more distinguishable as a result of familiarization, the LH, which appears to require a clear and complete representation to perform its processing efficiently, may then benefit more than RH from familiarization with stimulus. Thus, direction of the eventual shift in lateral differences become important. Most commonly a shift from initial LVF-RH advantage to a later RVF-LH advantage is observed (Beaumont, 1982; Goldberg & Costa, 1981). Umita et. al. (1978) compared performance on a face recognition task in which subjects were either familiar or unfamiliar with the stimuli. A RVF advantage was obtained for subjects who were familiar with the stimuli, but opposite outcome prevailed for subjects unfamiliar with stimuli (Hannay et. al., 1981; Sergent, 1982b).

The explanations of the above findings are a matter of hot debate. There is a large following for the thesis that hemispheric differences depend on the strategy typical of each hemisphere. (For example, Hannay et. al. (1981), suggested that

subjects showing LVF advantage used a "visuo-spatial mode of processing". However, before concluding that subject's strategy explains these shifts one might consider the role played by the characteristics of the input along with the task demands in terms of these characteristics, and examine whether both hemispheres could not use basically similar strategies performed on different characteristics of the incoming information. Thus, Sergent (1983) suggested that different stages of the same cognitive operation may be better performed in one or the other hemisphere, with RH more competent at preliminary processing and the LH at more detailed operations. This may indicate that both hemispheres are involved in any type of processing, but with differential sensitivity to the components of the sensory inputs.

Research Proposal

A critical survey of models of hemispheric lateralization and techniques used in the study of this phenomenon in previous sections, have lead to certain important conclusions about the nature of hemispheric specialization: (i) The old simplistic conception of LH as verbal/analytic and RH as visuo-spatial/holistic advanced to account for observed asymmetries, now appears to be inadequate because it has failed (a) to account for experimental data generated over the years, and (b) to make precise predictions about the nature of processing attributed to hemispheres in varied task conditions. Moreover, operationalization of these concept are not clear as they are stated in general and vague terms, instead, in specific and

generated a relatively detailed map of the human brain, but this map has necessarily limited spatial resolution and validity because of limited availability of brain damaged subjects, the uncontrolled, anatomically imprecise nature of human brain lesions, and the confounding effects of compensatory mechanism.

The rCBF technology was developed by Ingvar and his colleagues (Lassen & Ingvar, 1972; Ingvar, 1973). In this technique radio active 133 xenon is injected either into the jugular vein or the carotid arteries. The uptake of this isotope, which corresponds to the cerebral blood flow, is recorded by detectors. Increase in blood flow to a specific area of the brain relates to increased activation in that area. The major conclusion which can be drawn from these studies is that both hemispheres take part in the processing of any cognitive task, albeit in slightly different patterns (e.g. Larson, Ingvar & Skin hoj, 1978; Lechevalier et. al. 1989). The rCBF and PET techniques do have some methodological problems involving baseline standardization and sometime lengthy equilibration times are required before measurement may be taken. Still, they have already begun to yield impressive data.

Wada Technique: The wada technique is based on the use of anesthesia. The first use of local anesthesia to identify cerebral language areas was described by Gardner (1941). Procaine hydrochloride was injected directly into the cortex thought to potentially subserve language. In contrast to unilateral method of Gardner, the intracarotid amobarbital procedure developed by Wada (1959) affords the opportunity to access each hemisphere

contribution to cognitive function. In this procedure sodium amytal is generally used as transient anesthesia to anesthetize one hemisphere, thus evaluating the cognitive functions of the other. Study using this technique is conducted by Rasmussen and Milner (1977), to access the language capability of each hemisphere.

Clinical Techniques: Lesion and split brain studies have been important source of information about functional lateralization. It is on the basis of studies done using this technique which led to the formulation of the novel hypothesis of hemispheric asymmetry. Studies based on this techniques have also caught the imagination of scientists and lay public alike (Hellige, 1990). Indeed, it was the noting of relationships between injury to a particular region of LH and resultant specific language disorders that led Broca (1865), and Wernicke (1874) to postulate the importance of the temporo-parital area of the LH for language. Because LH is involved in aphasias it had been hypothesized by them that LH is specialized for linguistic activity.

This traditional view of LH language lateralization has been challenged in the recent years. Evidence has been gathered to suggest that a seemingly unitized cognitive function can be broken down into various processing subcomponents which are distributed across two hemispheres. For instance, according to such a complex conceptualization of cerebral lateralization, language is not seen as unitary ability as suggested by earlier aphasic research, but rather as a collection of syntactic, semantic and prosodic components with each lateralized in particular manners

(Palmer and Tzeng, 1990). The logical development of such conception of language is reflected in the work of Carammazza, Zurif and their colleagues (1983); who have concluded that Broca's aphasics are deficit in using syntactic information in both production and comprehension of language, in contrast to the earlier view that Broca's aphasics are only impaired on the production of speech. Similarly, they have reinterpreted Wernick's aphasia as deficit of using semantic information in both the production and comprehension of language, as against the earlier view which emphasized impaired ability to comprehend speech.

In split-brain studies the LH and RH are disconnected, and they do not communicate with each other. Probably, the most influential work in this area has been conducted by Roger Sperry and his colleagues using the "split-brain" or commissurized patients whose corpus-callosum were severed to medically treat patients of intractable epilepsy (e.g. Levy-Agrasti & Sperry, 1968) Levy, Trevarthon, & Sperry, 1972; Sperry, Gazzaniga, & Bogen, 1969). Post-operative testing of these patients produced data strongly suggesting that each of the brain's two hemispheres has differentially specialized functions in terms of perceptual and verbal processing. The RH appeared to be superior for visuo-spatial transformations, as well as recognizing faces and other complex visual patterns (e.g. Bogen & Gazzaniga, 1965; Nebes, 1971). In contrast, LH appeared to be superior for speech and calculation (Sperry, Gazzaniga & Bogen, 1969).

Sperry and his colleagues (e.g. Galin, 1975; Patterson & Bradshaw, 1975) were quick to point out, however, that the major characteristic of the two hemispheres may not be differential processing of perceptual vs. verbal information. Rather, they suggested that the major characteristic of the hemispheres is that each is specialized for a different cognitive or processing style. They suggested that LH appears to operate in an analytic, logical mode i.e. it processes information in a linear, serial or sequential manner and RH was seen as a holistic or "Gestalt" processor because it manipulates information in a more simultaneous or parallel fashion.

In cortical studies, the major problem with clinical method are in the description of lesion size, location, and etiology (Haalard & Yeo, 1989). Although lesion size and location can now be measured directly by radiological methods, recent studies have usually not considered lesion size even though it has been related to apraxia (Kertezz & Ferro, 1984). An additional problem with anatomical correlations is the validity of lesion size and location measures derived from CT scans obtained after an acute infarcts. Lesion location is usually defined by an experienced rater who designates whether a particular lobe or structure is damaged. Rarely in these studies intra rater reliabilities are included. The etiology of damage is also a potential confounding variable especially since more rapid onset problems, such as strokes, are likely to cause greater disruption in behavior and to be more reflective of the role of the damaged structure (Finger & Stein, 1982), in comparison to problems with gradual onset (e.g.

tumors).

Divided visual field technique: The key to this method is to present a visual stimulus for a very short duration in one hemifield only, while subject is asked to focus on a central fixation point. This short presentation time prevents subject from moving his/her eyes in order to focus on the stimulus and thus ensures that only one half of the retina is stimulated. Because the left part of each retina only projects into the LH and vice-versa, the method allows one to send information to each hemisphere separately. Thus stimulus presented in RVF has direct access to the LH, and the stimulus presented in the LVF is directly projected to RH. Cerebral processing of visual information can then be assumed to be initialed in the hemisphere contralateral to the visual field of presentation, provided two conditions are met: first, the stimulus must be presented to the left or right of fixation; second, the duration of exposure must be short enough (150 msec or less) to prevent eye movement that could expose the stimulus to both hemiretinae (temporal and nasal) of each eye.

These two conditions are the sine quo non of tachistoscopic studies in normals and they have been met without considering their effect on other properties of visual system (Sergent, 1983). There is considerable evidence that the visual system does not instantaneously extract the entire content of visual display. The extent of retinal eccentricity, the duration of exposure the level of luminance, and the size of stimulus are important factors in influencing the resolving power of the visual system and in

determining the quality of stimulus representation achieved in brain.

The analysis of the characteristic of divided visual field studies suggests that conditions during experimentation on hemispheric asymmetry influence the perceptual processes involved, and they may not do so equally for language stimuli and visuo-spatial stimuli. The viewing conditions in this technique are not optimal, thus, restricting the full utilization of processing capacity of brain. Verbal and nonverbal stimuli, as visual patterns, have different physical characteristics, are usually not equally familiar and are not subjected to same processing requirements. It is, thus, difficult to determine which of the many variables involved actually accounts for a faster or more accurate response in one visual field or the other. Moreover, information available through this technique is inherently state limited because usually response accuracy measures are taken under briefly exposed stimulus without speed constraints. Additionally, these measure are resource limited too, as response latency measures are also taken emphasizing speedy response (Norman & Babrow, 1975). On the basis of the above limitations, Sergent (1983) in her excellent review of role of the input in visual hemispheric asymmetries, has strongly advocated for the study of these limitations on subsequent processing.

Sergent (1983) has marshalled a good amount of data to show that implicit assumption in tachistoscopic method that visual system instantaneously extracts all the information contained in

the display is false. The temporal summation of energy varies as a reciprocal function of duration and intensity and Kahneman (1969) has suggested that higher acuity can be achieved at 300-400 msec. for spatial tasks. Additionally, experimental results seem to suggest differential hemispheric competence as a function of the quality of visual information - determined by exposure duration, and therefore stimulus energy - on which cognitive operations are performed. Usually RH is found to be superior at low exposure duration (e.g. Rizzolatti & Buchtel, 1977); low luminance (Hellige & Webster, 1981), and longer size of letters (Sergent 1982) for variety of tasks.

But there are some strong exception to the proposition that RH is superior processor at low exposure duration, low luminance etc. For example, a robust RVF advantage in the identification of briefly flashed familiar words is reported (Gill & McKeever, 1974).

Several interpretations of the above findings have been proposed, e.g., greater capacity of RH at extracting the critical features of degraded stimulus, or greater-visuo-spatial competence (Hellige, 1982) or, holistic mode of processing (Bradshaw & Nettleton, 1981); or RH perform better in conditions of stimulus uncertainty (Hick's law, Hick, 1952); or, being more 'vigilant' (Diamond, 1972), or, RH is more sensitive then the LH to the low levels of energy (Sergent, 1983).

Further, Sergent has also argued that different tasks used in divided visual field studies have specific processing requirement that may differentially engage the cerebral hemispheres, and the particular viewing conditions involved in these studies may help

examine the different capabilities of LH and RH. Thus, she argues that process limiting variables like memory involvement, discriminability of comparison stimuli, and familiarity or unfamiliarity of material will be important for hemispheric asymmetry.

The foregoing review hints at the importance of state-limiting and process-limiting variables for study of hemispheric asymmetry. Other limitation of visual half field technique is its sensitivity to ceiling and floor effects. Further, only a limited set of visual stimuli could be used in this technique.

Dichotic Listening Techniques: Perhaps the best known procedure for assessing laterality effects, particularly language lateralization (Geffen & Quinn, 1984), is the dichotic listening technique. These studies exploit the following characteristics of the auditory system. Auditory information is transmitted from each ear to both contralateral and ipsilateral cortical areas. However, contralateral pathways are stronger (they have greater number of fibers and higher transmission speed). The key to this procedure is to present information to both ear simultaneously, so that stronger pathways will occlude the weaker ones. In this way information can be presented to each hemisphere separately (Kimura, 1967).

Kimura (1961) demonstrated that pairs of language stimuli presented simultaneously to both ear are more accurately reported for right ear than for the left ear. Subsequent investigators have shown a REA for words, nonsensesyllables, backward speech, and synthetic syllables (Kimura & Fold, 1968; Shankweiller &

Studdert- Kennedy, 1967), and a LEA for nonspeech sound, music, environmental sound (King and Kinura 1972).

However, a few recent investigators have argued that REA effect may be brought about by a bias to selectively attend to the right side of space (Kinsbourne, 1970; Bryden, 1982; Treisman & Geffen, 1968; Geffen & Wale, 1979). The argument is that when subjects are left free to report the items, they may choose the order in which they report, and the way they attend to right and left ear stimuli (Bryden, Munhall, and Allard, 1983). Furthermore, Bryden (1982) has argued that it should be easier for right handed subjects to focus attention on items coming from right ear. Although he is not specific why it should be easier to "listen" to the right ear.

To meet the above criticism, investigators have developed an alternative paradigm in which subjects were presented with single-pairs of dichotic stimuli and they were instructed to only attend to and report the left ear input in one third of trials, to attend to and report the right ear input in another third, and to be free to allocate attention in either way in a final third of trials (Bryden, Munhall, & Allard, 1983). By comparing number of correct recalls from the left ear during forced attention to the right ear, with the number of correct recalls from the right ear during forced attention to the left ear, an "attention free" laterality score could be obtained. The logic behind this approach is that items reported from non-attended ear during the forced attention to the opposite ear should reflect intrusions from the contralateral hemisphere. Thus, if a REA exists for

non-attended items during forced attention, which is comparable to REA obtained during non-forced attention, then selective attention cannot alone explain the REA effect in dichotic listing. The validity of current paradigm can be increased if there is a pay off for forced-attention trials.

The concurrent Task-Paradigm: As noted above, cerebral dominance can be inferred from variety of experimental methods. The dual-task method is one which is currently generating much attention (Hicks, 1975; Hiscock et. al. 1987). Kinsbourne & Cook, (1971) suggested if two different tasks that depend on cerebral areas localized in the same hemisphere were carried out simultaneously, then a decrease in performance would be observed in at least one of these tasks. The concurrent-task technique is based on the above rationale. For instance, if an individual is right handed, speech production and control of right hand motor program are usually mediated by LH while the control of left hand motor program are usually mediated by RH. Consequently, speech production interferes more with right hand tapping than left hand tapping (Bowers et. al., 1978; Dalby, 1980; Hellige & Longstrth, 1981). The dual task paradigm can elicit competition between two output processes (e.g. finger tapping and speaking), or competition between an output process and a cognitive process (e.g. face encoding and tapping). Interestingly, most dual task studies have found that when performance on both manual and nonmanual tasks is measured, unimanual tapping rarely has a lateralized effect on either verbal production or cognitive processes (Kinsboume & Hiscock, 1983a). Conversely, tapping has

been found to get disrupted asymmetrically with performance on face encoding and verbal production (McFarland & Ashton, 1978b, Wiegersma & Wijnmaalen, 1991).

Following Brinkman & Kuyper's (1972) suggestion that the activity of each hand is controlled by contralateral hemisphere, most of past researchers in this area employed unimanual tapping as concurrent motor task (Hellige & Longstretch, 1981; Cremer & Ashton, 1981).

Recent discussions of dual task research have emphasized some methodological concerns (Green & Vaid, 1986; Green & Weller, 1989; Hiscock, 1986). The suggestions advanced for improving the procedure's validity include (1) manipulating the task difficulty to assess for task influence on outcomes including possible ceiling effects, (2) employing at least one task that produces more than minimal disruption in concurrent activity, (3) performing task reliability assessment, and (4) establishing a baseline level of performance for both cognitive and manual task to ensure that no attentional trade off occurs.

Several investigators have studied the effect of concurrent cognitive tasks upon unimanual performance (Diamond & Beaumont, 1971; Hicks, 1975; MacFarland et. al., 1989). Kinsbourne & Cook (1971) found that a practical balancing task performed with right hand was disrupted by concurrent verbalization, which has also been found to interfere more with several other manual activities performed by the right hand than with the manual activities performed by the left hand (Podbrows & Wyke, 1988).

The effect of performing a cognitive task concurrently with a

tapping task depends on the cognitive task that is being carried out and the hand which is employed in tapping. For instance, it is reported that linguistic tasks adversely affect right hand tapping (McFarland & Ashton, 1978b). Left hand tapping gets affected by simultaneous performance with modified EFT (Cremer & Ashton, 1981; Santhakumari, 1985).

Kinsbourne (1973) has offered "functional cerebral distance principle" to account for aforesaid findings. This principle posits that two concurrent activities interfere with each other to the extent that they share the same functional cortical space. Tasks are considered functionally close to each other in terms of the neural areas involved in the performance of the tasks. With few exceptions, functional cerebral distance is proposed to be shorter within a hemisphere then between hemispheres and in this way hemisphere specific interference is predicted.

A number of studies have found that speech disrupts concurrent right hand activity more than concurrent left hand activity (see Hiscock, 1986, for a review). A general explanation for these findings is to evoke kinsboure's principle. Because the LH mediates both the speech and right hand activity, consequently, there is competition for the functional resources of the LH. Conversely, left hand activity is mediated by RH, therefore, it does not compete with speech task for processing resources.

Lomas and Kimura (1976) and Kimura (1979) offered a refinement of this account and proposed that the source of interference between right hand activity and linguistic task lies in two tasks competing for a specific LH motor control system

which is specialized for mediating the rapid-repositioning of musculature. This LH motor control system is seen to mediate both manual and oral musculature (e.g. as required in speech). Thus, Kimura (1977) found that aphasic patients with LH injury were also more impaired on a manual sequencing task than non-aphasic patients. Moreover, findings of Mateer & Kimura (1977) supported the thesis that both oral and manual rapid-reposition movements are mediated by a common LH "rapid-repositioning movement center". They found that fluent aphasics who did not show a deficit on producing single oral movements (e.g. Saying, ba, ba, ba ..), were significantly impaired in producing multiple oral movements (e.g. ba, da, ga,), relative to each of two non-aphasics groups. They also showed that the aphasic patients were impaired in the production of meaningless non-verbal oral movement sequences and their speed of finger-tapping on a concurrent task is asymmetrically disrupted. Kimura (1979) argued that such evidence suggests that LH specialization is not limited to linguistic, verbal, or representational movements, but applies to any movements requiring rapid repositioning of musculature.

The end point of such a theory is that the specialization of function in the LH can be considered not in terms of verbal or cognitive processes per se, but rather in terms of neural structures specialized to mediate specific forms of activity (Kimura, 1977, 1979, 1981).

Sex Differences

Gender related differences in lateralization have been suggested in various functions: spatial processing (Witelson,

1976); representation of melody (Piazza, 1980); facial recognition (Safer, 1981), and hemispheric representation of language (McClone, 1978). Generally the verbal differences are small, mathematical differences are large, and visuo-spatial differences are largest (Halpern, 1986).

The concept of Sex differences in inter hemispheric organization of language was originally suggested on the basis of more severe impairment of verbal intelligence in males following left temporal lobectomy (Lansdell, 1962; Lansdell & Urbach, 1965). Sex differences in cerebral processing of visual tasks have been suspected on the basis of more impaired Block designs on Raven's colored progressive matrices scores in males with RH lesions when compared to females (McClone & Kertezz, 1973). It was also suggested that females may become aphasic less often with LH lesions on the basis of small sample of patients (McClone, 1977). However, an epitemiological study of aphasics and cognitive impairments following stroke suggest that a higher male-to-female ratio in aphasic population was related to the distribution of cerebral infarcts rather than to the sex differences in cerebral organization (Kertezz & Sheppard, 1981).

McClone (1978) reported that verbal IQ deficits in women with left side damage did not differ from those of either men or women with damage to the right side of brain. In contrast, verbal IQ deficits in men with left injury were significantly greater than any other group. It was, thus, concluded that right handed men demonstrated a greater degree of functional asymmetry with respect to language than do women. This thesis is supported by many

investigators using different methods (Bertler, 1985; Lake & Bryden, 1976).

The other side of story is that not all reports confirm the findings sketched above. Thus, Basso, Capitani, and Moraschini (1982); Brust et. al. (1976) and Kertezz & Sheppard (1981), all failed to find sex differences in aphasic. McClone (1980) reviewed 14 dichotic listening studies, and found that nine reported null reports to sex differences, one found evidence for greater LH language function in women, and only four indicated bilateral language representation in female subjects. Similar findings were also obtained in reviews of FearWeather (1982) and Deutsch (1985). A recent study by Kertezz and Benke (1989) used computer tomography to determine the location of lesions. No sex differences in incident of anterior, posterior, or central lesions was reported. The distribution of LH lesions in stroke patients with or without aphasia was equal among sexes. This study contradicted Kimura's (1983) report which proposed that females less often become aphasic following left posterior damage than males and that some functions dependent on left posterior speech system in males may be subserved by left anterior region in females.

One notion that has emerged from wealth of conflicting evidence is that sex differences do not manifest themselves in gross functional asymmetry but, rather, as differences of responses to particular task requirements. Thus inconsistencies in findings may reflect subtle change in task demands imposed in different studies.

Practice Effect

Changes with practice in the observed pattern of lateral differences have often been reported in laterality studies (Beaumont, 1982). These effects are not well understood and the origin is usually attributed to unspecified kind of noise. For Young (1982) effects of practice reported in the literature are complex and inconsistent. Studies have not been successful in disentangling effects attributable to practice of given tasks from those that may have arisen from increased familiarity of stimuli and from covert and overt changes in subject strategies. The problem is difficult because several factors might partially and simultaneously account for these practice effects (e.g. number of trials in the experiment; nature of practice session; nature of stimuli; the nature and difficulty of task, the familiarity of material and procedure, the number of rest phase etc). In addition, because performance usually improves with practice, one has to avoid a progressive extinction of lateralized difference due to a floor or ceiling effect. Beaumont (1982, pp. 82) gave another explanation. "... an increased adaptation to the unnatural process of attending to strongly lateralized presentation .. may reflect a more fundamental adaptation and rearrangement by which the relative lateralized nature of the processing system is modified to compensate for the asymmetry in performance in the two visual fields".

Several experiments have examined the influence of familiarization on hemispheric processing of previously unfamiliar stimuli. It should be noted that absolute discrimination in sense

of extracting the invariants of instances of a category (Harnard, 1981) is not involved in such cases, and only one instance of unique stimuli is subjected to familiarization. This suggests that processes are still performed on neural "analogues" of the physical characteristic of stimulus. However, one effect of familiarization is to increase the prominence of the relevant physical dimensions of a stimulus (Pick, 1965). Shepp (1978) has shown that there are additional progressions in the perceived stimulus structure that emerges in course of perceptual learning . If the relevant perceptual features of a stimulus become more distinguishable as a result of familiarization, the LH, which appears to require a clear and complete representation to perform its processing efficiently, may then benefit more than RH from familiarization with stimulus. Thus, direction of the eventual shift in lateral differences become important. Most commonly a shift from initial LVF-RH advantage to a later RVF-LH advantage is observed (Beaumont, 1982; Goldberg & Costa, 1981). Umita et. al. (1978) compared performance on a face recognition task in which subjects were either familiar or unfamiliar with the stimuli. A RVF advantage was obtained for subjects who were familiar with the stimuli, but opposite outcome prevailed for subjects unfamiliar with stimuli (Hannay et. al., 1981; Sergent, 1982b).

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precise terms. (ii) Experimental findings, particularly findings from rCBF, have demonstrated that both hemispheres of human brain are engaged during processing of any cognitive task, albeit in slightly different patterns. Therefore, conclusions such as language being LH task and visuo-spatial dimension being RH task, appear to be false and misleading. Recent reviews have rejected tha idea of a strict dichotomy between hemispheres (Beaumont, Young, & McManus, 1984) and have considered differences in hemispheric functions as being not only qualitative but also quantitative (Bradshaw & Nettleton, 1981; Sergent, 1982b; Santhakumari, & Sharma, 1990). In this line of thought, Zaidel (1983), followed by Bruyer (1986), argued in favor of a model of "relative specialization" versus "exclusive specialization." In contrast with the model of exclusive specialization, relative specialization acknowledges that some tasks can be performed by both hemispheres, although not necessarily with equal competence. (iii) Reviewed experimental data, however, have also suggested that hemispheric asymmetry is a pervasive phenomenon demonstrated by use of different techniques under different task conditions.

These conclusions have led to the view that hemispheric asymmetry can be understood in terms of computational models. The central proposition of such a view is that cognitive tasks consist of a number of basic elements and these elements are processed by different subprocessors localized in LH and RH. Thus, hemispheric asymmetry refers to the asymmetry of these subprocessors in dynamic and interactive way. In light of this, Kosslyn (1987,

1988) has formulated that visual-spatial tasks are carried out by a categorization subprocessor which specifies the relational property of objects (e.g. "above", "below", etc.). Kosslyn further hypothesized that categorization relations are better computed in LH. Similarly, RH is supposed to do better at coordinate subprocessing which specifies the precise location of object using metric coordinate system. Additionally, researcher have formulated image generation process and image transformation process for imagery, supposedly carried out effectively in LH and RH respectively (Farah, 1986). It should be noted here that these dichotomies are computational and molecular in nature as they posit that visual-space perception may be made up of different components.

Further, Sergent (1983, 1987, a, b) has emphasized the role of input characteristics as clear from afore-mentioned review. She holds that energy content of stimuli in terms of high or low spatial frequency is an important factor in the observed asymmetries. Thus, she hypothesized hemispheric asymmetry in terms of high versus low spatial frequency content of input information. She has further stated that high spatial frequency input is processed more effectively in LH and low spatial input in RH.

On the basis of the above, it can be concluded that there are models of hemispheric specialization which emphasize input characteristic of stimulus to account for observed asymmetry and, still, there are other models which are formulated in terms of

processing specialization of LH and RH. These conclusions point towards lack of an unifying model which could explain the nature of hemispheric asymmetry in a more parsimonious way. Although Allen (1983) advocated for need of such a model which could integrate the unifying mechanism of different models and precisely predict under what set of task/situation LH and RH processors would be effective. Therefore, any future model of hemispheric asymmetry must formulate (i) how task characteristics (including the viewing condition prevalent in experiments) are related to hemispheric lateralization, (ii) what is the nature of LH and RH processors, and (iii) what are the relationships between task characteristics and processing capabilities of LH and RH processors.

The Proposed Model

The reviewed literature suggests that both hemispheres are engaged in processing of cognitive tasks, though, they may differ in competence. Moreover, data also supported the notion that elementary operations forming the basis of cognitive tasks are strictly localized. Therefore, a set of distributed brain areas must be orchestrated in the performance of cognitive tasks (Posner et. al. 1987). The task itself is not performed by any single area of the brain, but the operations that underline the performance are strictly localized, thus, computational requirement of cognitive tasks. Another important feature of reviewed data was that certain operations are not only localized, but also lateralized. Therefore, certain kind of operations are

better carried out in LH or RH. Last important feature discernable in reviewed data was the role of input characteristics in hemispheric asymmetry.

Based on the above features of data, it is attempted here to outline a model of hemispheric asymmetry which will be, more parsimonious than any other model because (i) the model has internal consistency as it takes into account all the important features of reviewed data; (ii) it explains more data then any other model because it tries to synthesize unifying mechanisms of different models into proposed model; and (iii) it makes clear and precise predictions which makes the falsification (Popper, 1963) and improvement of the model possible. Moreover, the model also postulates some new mechanisms, hither to unproposed, to clarify and sharpen the concept of hemispheric asymmetry.

The model postulates two kinds of processors in the brain (i) the generalized processor (GP), and (ii) the specialized processors (SPs)of RH and LH. Generalized processor is a bilateral processor, that is, both hemispheres have this processor. This processor is capable of processing elementary tasks. This processor may be localized for different cognitive tasks, but this is not lateralised. The anatomical loci of this processor is determined by input characteristics of stimulus. This processor is connected to interhemispheric and intrahemispheric specialized processors of LH and RH. The rationale behind the postulation of generalized processor is: (i) The different techniques that allow simultaneous monitoring of

both sides of the brain or body (e.g. dichotic listening, visual half field, concurrent task, evoked potentials and rCBF, techniques etc.) show that both sides of brain show some activity. (ii) Human beings are constantly bombarded by multitude of perceptual and motor tasks demanding rapid, simultaneous, and coordinated performance from both sides of body. Thus, it is a plausible inference that both hemispheres are acting simultaneously. Additionally, generalized processor is supposed to work on redundancy principle i.e. both hemispheres engaged in similar processing depending upon sensory field of presentation of stimuli. Generalized processor carries out processing at elementary level of task difficulty without active requirement of attentional efforts. Joel Fagot and Jacques Vacuclair (1991) in an excellent review of manual laterality in primates made a distinction between low-level tasks and high-level tasks. High-level task implies finely tuned motor action because of the spatial temporal dimensions of movement required, or cognitively complex activities (or both) involving, characteristics of novelty and difficulty. By contrast, low-level tasks concern grossly regulated activities on familiar, practiced activity, or both. They have noted that this dichotomy represents a minimal classification of a graded continuum of novelty difficulty / easy-practiced dimensions. As a prediction, it is hypothesized here that only on low-level task processing is done by generalized processor. Therefore, this processor should not yield lateralized interference on low-level task but a generalized interference is

possible, if more then one low-level task is carried out simultaneously in concurrent task paradigm.

Generalized processor is an intelligent processor i.e. it knows about its capacity limitation as well as addresses of specialized processors. If input task exceeds the capacity limitation of the generalized processor, either because of nature of task as high-level task or because task is data limited, it switches the processing to specialized processors. Specialized processors are tuned to process high-level tasks. Depending upon the nature of task different kinds of specialized processors are engaged for processing. These processors are localized as well as lateralized i.e. different specialized processors are more or less effective in carrying out only certain kinds of computations on high-level task.

Another important thing to be noted here is that a low-level task may become a high-level task if it is processed under data or resource limited condition. This assumption is important to explain the observed discriminative reaction time differences between sensory fields at low level tasks. Levy (1974) has accounted for such differences in terms of competence or incompetence of particular hemisphere to accomplish the task. If a hemisphere is not competent to carry out the task, then Levey hypothesized that message must be sent back to reticular formation, which must stop sending arousal input to incompetent hemisphere and then shunt or allocate arousal input to competent hemisphere. On the other hand, core assumption of the model

presented here is competence of both hemispheres on low-level tasks of all kinds. Thus, Levy's explanation would be contrary to proposed model. Therefore, proposed model accounts for such differences in terms of data limitation of task which makes a low-level task as a high - level task leading to lateralized interference. A logical corollary of such explanation would be that, had the same task being processed in absence of data limiting condition, no such difference should be observed at low-level tasks. Testing of this corollary may reflect on the relative parsimonious explanatory value of Levy's account in comparison to the account proposed here.

Moreover, it is hypothesized that RH / LH specialized processors do their computation on random /rule based principle. Random processing here does not mean haphazard processing but processing in relatively unprogrammed way with in built uncertainty. On the other hand, rule based processing is defined as programmed processing with in built certainty. This assumption is derived after analysis of input characteristics and processing capabilities attributed to LH and RH. It is stated that RH processors do better processing at low spatial frequency level, or when they compute coordinate relation, or when they do holistic processing. Similarly, it is attributed that LH processors, do processing in better way at high level of spatial frequency; or at categorization process; or when they are doing analytical processing. If we analyze the kind of property being attributed to RH processors, we discern that attributes which underline all

above processes are attributes of randomness i.e. non-programmed nature of processing and some degree of uncertainty involved in processing when compared with invariants of physical world. For example, if an input is data limited, it will not be possible to carry out rule based processing because rule based processing by definition requires detailed and total input. Similarly, if we take, for instance, coordinate and categorization process, it would be clear that coordinate computation is more random than categorization computation because in case of category relation (e.g. "above",), either category is present or absent as per program. Thus here is high degree of certainty. On the other hand same is not the case with coordinate relations where distances have to be specified based on subjective referent, with some degree of uncertainty. Figure 1.1. presents a schematic diagram of the proposed model.

Rationale of Experiments: A critical survey of reviewed literature yielded following issues for the experimental investigations.

(i) To carry out an empirical testing of proposed model of hemispheric asymmetry.

As discussed in the previous section, the proposed model makes some specific predictions about the nature of hemispheric asymmetry. It predicts that at low-level task, there would be an active engagement of both hemispheres, provided task is not data limited. Moreover, it also posits that as the task is shifted towards high-level task (either because of novelty or difficulty)

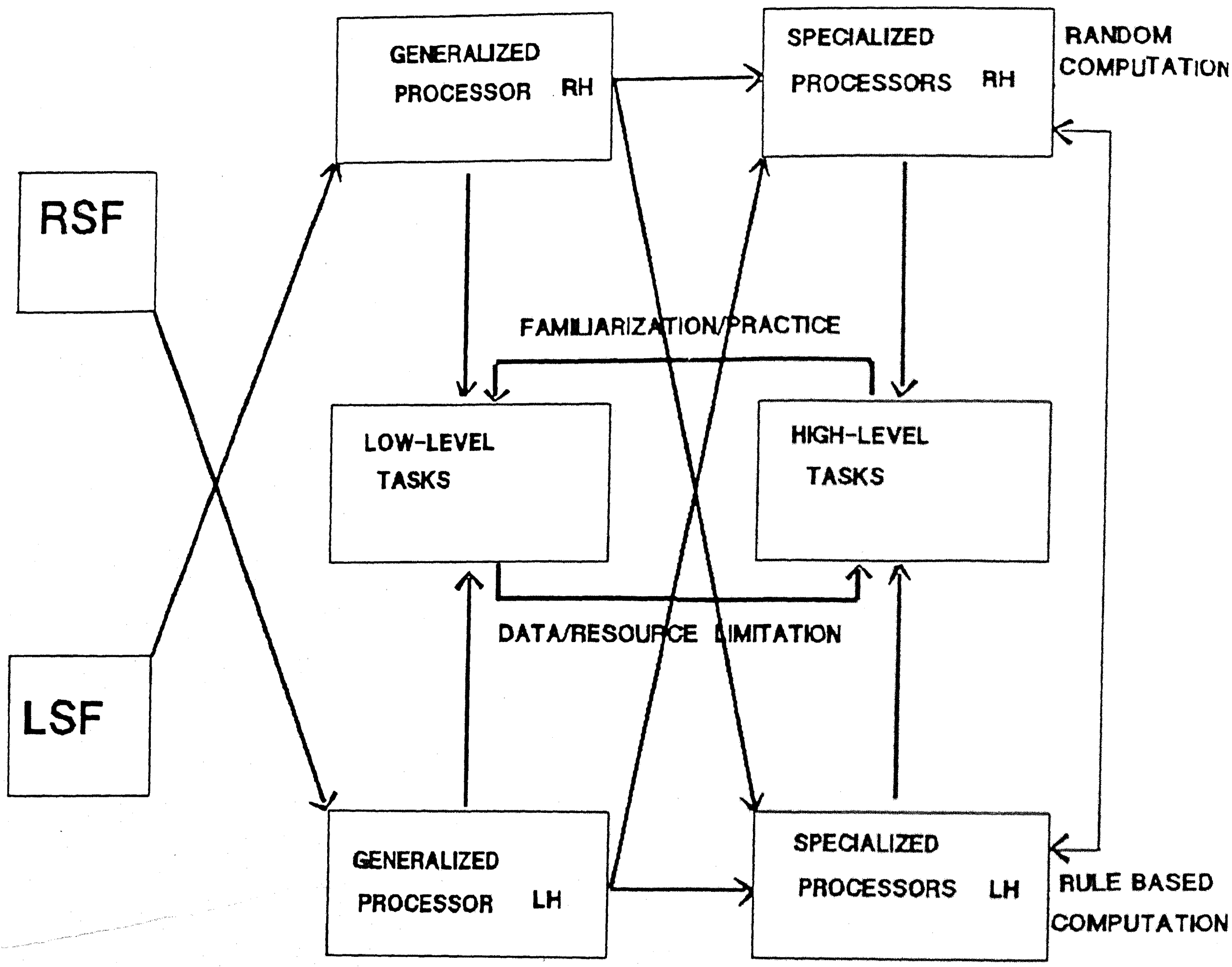

Figure 1.1: Schematic Diagram of the Proposed Model of Hemispheric Lateralization. Abbreviations : LSF = Left Sensory Field, RSF = Right Sensory Field.

then there would be an asymmetric shift in processing. If task is rule based, then efficient processing by specialized processors of LH is predicted and if the task is non-programmed, then vice-versa would be true. A corollary to this hypothesis would be that with increased familiarization both hemispheres would engage in processing of task because task will become a low-level task and processing load will be shifted from specialized processors to generalized processor.

The above predictions were tested in a series of four experiments, numbered as 1A, 1B, and 2A, 2B. In experiment 1A, it was suggested that by varying the difficulty of task, thus requirement of rule based processing, it would be possible to see whether lateralized interference is observed or not in concurrent task paradigm. It was hypothesized that as the difficulty of tapping sequence is increased hemispheric processing would become lateralized from initial bilateralism. Additionally, the number of practice trials is used as an independent variable to see whether familiarization results in bilateral processing or not, from initial lateralized processing.

(ii) To test the relative explanatory value of proposed model as compared to the "rapid-repositioning center" model of Kimura (1977) to account for the observed verbal and motor lateralization.

As mentioned earlier, Kimura (1977) and her associates proposed the rapid repositioning center view to account for the verbal and motor lateralization. According to such a view, the

source of interference in concurrent task paradigm lies in two tasks competing for a LH motor control system, rapid repositioning center as they call it. Thus, Kimura (1977) reported that aphasic patients with LH injury were also impaired on the manual sequencing task. The proposed model would have reinterpreted such findings in terms of rule involved in carrying out any sequential motor activity. Such interpretation assumes that any kind of oral or musculature repositioning will have a rule component and it is because of involvement of this component that efficient processing in LH is reported on such tasks. To test the notion, an experiment was carried out in which rapid-repositioning of finger musculature was contrasted against rule basedness of such repositioning under two conditions (a) on a task requiring very repaid-reposition of finger movement against (b) another task requiring more complex movement program of finger but having less rapid-repositioning of finger-musculature.

(iii) To test the claim that verbal production is mediated by LH against the prediction of proposed model that only high-level verbal production task requiring attentional processing would be lateralized in LH whereas low-level tasks such as verbalization of a paragraph without requirement of comprehension would lead to generalized interference only.

It is generally reported that speech production is mediated by LH (Hicks, 1975; Kinsboune & Hiscock, 1983a). But what is not clear is whether all kinds of verbal production is mediated by LH or only speech production on high level task as the proposed model

predicts. The model predicts that low-level task of speech production (e.g. automated reading of paragraph) should show bilateral processing and only speech production requiring active attention should show lateralized processing. To test the prediction, in experiment 1B, subjects were asked to articulate the sequence they were tapping. It was hypothesized that such meaningless verbalization would not change lateralization pattern. In experiments 2A and 2B subjects were consecutively asked to read the paragraph as fast as possible, or with a view to comprehending it. It was hypothesized that only on latter condition lateralization would be observed.

(iv) As is clear from reviewed literature, sex related findings were equivocal in nature. Thus they need further investigation. In this light, sex was included in experimental studies.

CHAPTER 2

EXPERIMENTAL INVESTIGATION

Contents

An Overview

The present work is a step towards understanding the nature of hemispheric asymmetry. With this in view, a general model of hemispheric asymmetry was presented in Chapter I and the assumptions of the model were outlined. It was suggested that the proposed model is a more parsimonious model of hemispheric lateralization than any other model because (i) the model has internal consistency as it accounts for all important features of data generated over the years in this area; and (ii) its predictions are precise and specific thereby making the model empirically verifiable or rather empirically falsifiable (Popper, 1963).

This chapter contains the experiments which were carried out to meet the objectives of (i) initial empirical testing of the model, and (ii) reinterpreting certain experimental results in more parsimonious way. To test the predictions of the model and to develop a more coherent conception of hemispheric asymmetry, four experiments were carried out. These experiments were numbered as 1A, 1B, 2A, and 2B. The strengths of these experiments were their model testing ability, sophisticated data collection techniques, and precise controls. These experiments are described in terms of method, results, and discussion.

Before presentation of empirical findings it would be pertinent to say a few words about the writing style of the chapter. Statistical analyses were carried on two sets of data: (i) Non-transformed data called as NT-data, and (ii) Transformed

interference in the tapping performance of right hand because in such condition specialized processors of LH would be required to accomplish the complex sequential motor task. The logic behind this hypothesis was that a complex sequential motor task would consist of (i) a motor component, and (ii) a rule component and rule component would be effectively carried out by LH processors, leading to interference in RH tapping rate.

(ii) To re-examine Kimura's (1977, 1979, 1983) hypothesis of "rapid-repositioning motor center" which she has proposed to account for the observed lateralized interference in RH performance for verbal production and muscle repositioning tasks in the concurrent task paradigm. As refinement to her model, the proposed model would have accounted for such results in terms of rule involved in any muscle repositioning task. Thus, second aim of this experiment was to test the relative parsimony of Kimmura's model against the proposed model to account for the muscle repositioning data. Following specific research hypotheses were stated:

H_1: A shift in experimental task from low-level task to high-level (as a result of increase in complexity of the rule to be followed to carry out the muscle repositioning task, than regardless of rapidness of such muscle repositioning) produces more disruption in right hand tapping than in the left hand tapping.

H_2: The more difficult the program to carry out the motor sequence, more is the interference in right hand tapping as compared to left hand tapping and such interference is lateralized also, when compared against a mathematically neutralized baseline tapping.

H_3: There is no sex difference on H_1 and H_2.

Method

Experimental Design: A 2 (Sex: male, female) x 2 (Hand: Right hand and Left hand) x 4 (Familiarization; Practice over four Trials) x 5 (Task conditions) factorial design was used with repeated measures on the last three factors.

Subjects: Ten males and ten females participated in the experiment. They were in age range of 18 - 30 years. These subjects were drawn from the undergraduate and post graduate classes of Indian Institute of Technology Kanpur. All subjects were self declared right handers.

Stimulus material: For this experiment, five tapping sequences of varied lengths involving tapping of the keys `V' and `N', were developed. The following five sequences were used in experiment 1A. The mathematical program of these sequences are given in the bracket.

1.	D1	-	V (1); or N (1)	(baseline sequence)
2.	D2	-	VN (1:1)	(concurrent sequence)
3.	D3	-	VNNVVN (1:2:2:1)	"
4.	D4	-	VNNVVN, NVVNNV (1:2:2:1, 1:2:2:1)	"
5.	D5	-	VNNNVVNNVVVN (1:3:2:2:3:1)	"

Sequence D_1 served as baseline sequence. In this sequence subjects were required to tap either 'V' or 'N' key using middle or index finger. Sequences D2-D5 served as concurrent condition sequences. These sequences (D2 -D5) progressively consisted of more and more difficult rule (motor program).

As can be seen from the close scrutiny of sequences, both muscle-repositioning (lifting of fingers from said keys) and rule (program or step) to be followed to carry out the sequences were varied. In conditions D2-D5 subjects were required to tap the keys in the defined sequence using index and middle fingers. Index finger was used to tap the 'V' key and middle finger was used to tap the 'N' key. The subjects were instructed to tap the key instead of keeping it pressed by the required finger. D2 was used as sequence requiring the highest amount of muscle repositions as subjects had to tap only once at a time on 'V' and 'N' keys. On the other hand, the sequences D3-D5 were used as sequences requiring lesser amount of muscle repositioning as is clear from their structures. But sequences D3-D5 required more complex tapping rule. Thus muscle repositioning requirement was relaxed as the tapping rule became more complex.

Instrumentation: Two keys ('V' and 'N') of a personal computer were used as tapping keys. A computer program was developed to record the total number of taps within a given time-interval (15 sec.) as well as the number of times the particular sequence was tapped incorrectly. The main features of the computer program are as follows:

(i) Any sequence made up of up to twenty characters (e.g. verbal, arithmetical etc.) can be defined and stored (called standard sequence). A particular sequence can be exposed for inspection for predicted duration of 1 minute. After inspection time is over a plus (+) sign in the middle of the computer screen serves as signal to the subject to start tapping. The sequences tapped by subjects are matched with stored standard sequences and error in tapping of the defined sequence is computed.

(ii) A predecided time interval can be set for tapping task. This time interval can be varied on different trials or in different experiments as per requirement of the study.

(iii)After predecided time interval is over, computer echoes the preliminary analysis of data which gets displayed on the screen and which serves as signal for subjects to stop tapping. The preliminary results include number of taps in given time interval, tapping time, reaction time to initiate tapping, number and percentage of correct and incorrect responses as well as rate of tapping (taps/sec.).

Procedure: Each subject was individually tested in a quitte room . The subject was told that he had to tap the sequences shown on the monitor set of the PC. The sequence consisted of letters 'V' and 'N'. He was instructed to tap as rapidly as he could while maintaining accuracy. The experimenter demonstrated the key tapping procedure to the subject without allowing him to practice for himself. After this, he was shown the standard sequence for 1 minute which he was supposed to tap. The Subject was asked to rate the difficulty of the sequence by assigning

ranking of 1 to 5, where 1 stood for the easiest sequence and 5 for the hardest one. Thereafter, subject was instructed to start tapping the inspected sequence as soon as plus sign (+) appeared in the middle of the computer screen and stop tapping as soon as the results were flashed on the screen. In Experiment 1A, the provided time for tapping was 15 seconds for baseline as well as concurrent conditions. In all, each subject was required to tap all the five sequences by left and right hand on four trials. A trial consisted of tapping by LH and RH under all the five conditions. The order of presentation of sequences to the subjects was random on a given trial but tapping by left and right hand was counterbalanced across the trials. A five minute break was given after expiry of two trials. The experimental session lasted for approximately half-an hour. After the experimental session was over, the subject was again asked to rate the perceived difficulty of the sequences. Furthermore, each subject was randomly tested for memory of longest sequences and it was found that they did remember all sequences. Thus, one minute inspection time for each sequence was sufficient for perfect memory.

Scoring: The computer program computed tapping rate (number of taps/second) for each subject which was used for further analysis. Repeated measures ANOVA was used for analysis of the data. A computer program was developed for this purpose as SPSS package does not have the program for such analysis. Error data were also recorded but no further analysis was carried out on this set of data because the basic aim of collection of error data was to ensure that subjects did not differentially allocate attention to

speed to the tapping task. The difficulty levels of sequences were determined by rankings assigned by subjects to sequences before and after the experiment. Assessment of processing requirement of sequences provided by two colleges of experimenter were also obtained. Sequences were arranged in orders of their difficulty in the section on 'stimules material' above.

Results

Since the dominant hand generally produces more taps in a given time interval than the non-dominant hand in baseline tapping condition, it is necessary to use a measure of interference which mathematically neutralizes the advantage of dominant hand in baseline tapping condition. The measure of interference traditionally used is a percentage change score (Kinsbourne & Hiscock, 1973). Willis and Godwin (1987) have noted that such indices have strong limitations because (1) raw scores are not used, and (2) they have low reliability. They have also questioned interpretation of dual task outcome: "A potential problem with raw score generated through these paradigms is that they may be insensitive to lateralised interference effects. This is because participants are usually right handed and inter hand comparisons of initial (i.e. baseline) tapping typically favor the right. Given this initial discrepancy between hands, differential interference effects associated with the concurrent performance of an unrelated task may be due to initial differences in tapping speed rather than lateralization effects. In this respect, interference might be greater for right than left handed tapping because, due to higher range of initial values from the right

hand, there is higher possible range for reduction".

In response to above criticism, Kee and Cherry (1990) found that even after removing the initial right hand advantage experimentally in baseline tapping, lateralized interference was produced by concurrent anagram solution. To ward off such criticism a related task was used as concurrent task in the present experiment. In fact, an enterprising variation of concurrent task paradigm was used in the present experiment. Instead of using a motor task and another cognitive task, a motor task of five difficulty levels of repositioning was used. The simplest motor task served as baseline task and other sequences served as concurrent (successive) tasks. It was hypothesized that complex motor sequence consists of two components: (1) a motor component, and (2) a hypothesized rule component involved in that sequence. Thus, sequential motor task was considered as dual task because it envisaged differential processing by LH Processors owing to involvement of rule component in the motor tasks.

Moreover, in the present experiment a comparison of right and left hand tapping was provided under two conditions (i) right hand advantage present at baseline (or NT-data), and (ii) right hand advantage neuralised at baseline (or T data). Second condition was achieved by multiplying the raw scores of right hand with a coefficient which was arrived at by dividing the LH tapping rate by corresponding RH taping rate under baseline condition. Thus the data were transformed under the assumption of equality of tapping for the RH and LH tappings under baseline condition (D1).

That is, RH and LH tapping rates were equated under D1 for each block of trial for each individual subject and a coefficient (k) was determined.

$$k = \frac{\text{LH baseline tapping rate}}{\text{RH baseline tapping rate}}$$

Since all subjects were self declared right handers, k was expected to be less than unity. This was actually found. For each block of trial consisting of D1 - D5 task conditions the value of k was different. RH tapping rates for concurrent conditions (D2 - D5) within each block of trail were transformed using the relation.

$$T_{RH} = k \quad NT_{RH}$$

Where T_{RH} = Transformed tapping rate for RH

k = Coefficient

NT_{RH} = Non Transformed tapping rate for RH

Both sets of data (NT-data and T-Data) were statistically analyzed. Appendix 1(A1) presents mean taps per second for males and females under different Task conditions (NT-data).

A four-way repeated measures ANOVA revealed significant interaction amongst hand, practice trials, and task conditions for NT-data (Appendix 2). In order to examine the nature of interaction, simple interaction effects analysis as well as simple-simple effects analysis were carried out (see, Appendix 2A). As can be seen from Appendix 2A, simple interaction for hand x task conditions, and trials X task conditions turned out to be

significant. Further decomposition of data showed that right hand tapping performance was superior under D1 and D2 task conditions as compared to left hand, performance, but on the remaining task conditions no such difference was noted. Since the right hand advantage was not neutralized in NT-data, the data were transformed mathematically as per procedure described above and further analysis were carried out.

Table 2.1 shows the mean Taps/second and standard deviation for males and females in different task conditions on T-data. Figure 2.1 presents the average performance of each hand as a function of the difficulty level of the task conditions.

A four-way repeated measures ANOVA on T-data revealed a significant hand x task condition interaction ($F = 5.39$; $df = 1, 45$, $p < 0.01$) and practice trials x task conditions interaction ($F = 7.73$; $df = 12, 72$; $P < 0.01$). Decomposition of hand x task conditions interaction showed that right hand tapping was more disrupted than the left hand tapping under D3 - D5 task conditions ($F = 11.44$, 15.75, and 17.33; $df = 1,18$, $p < 0.01$), but no such difference was observed under D1 and D2 task conditions (see Figure 2.1 for D2 task condition). Moreover, right hand performance amongst the concurrent task conditions differed significantly ($F = 139.47$, $df = 4,72$, $p < 0.01$ and Figure 2.1) and so did the left hand performance ($F = 120.53$, $df = 4, 72$ $p < 0.01$). Simple analysis of task conditions x practice trials interaction showed significant difference among task condition on all the four trials (refer Figure 2.2 and Table 2.3). Similarly, effect of practice trials was found to be significant on all the task

Table 2.1

Mean Taps/Second and Standard Deviation for Baseline (1) and Concurrent Task Conditions (2-5) for Males and Females (Experiment 1A)

Conditions		Males		Females	
		Right Hand	Left Hand	Right Hand	Left Hand
1.	Mead	6.16 (5.40)	5.40	6.01(5.23)	5.23
	S.D.	0.69 (0.65)	0.65	0.59(0. 73)	0.73
2.	Mean	3.95	3.91	3.73	3.76
	S.D.	1.52	0.92	1.22	0.98
3.	Mean	2.78	3.07	2.73	2.98
	S.D.	0.92	0.67	0.75	0.65
4.	Mean	2.66	2.84	2.66	3.10
	S.D.	0.70	0.68	0.72	0.75
5.	Mean	2.23	2.48	2.18	2.57
	S.D.	0.55	0.51	0.66	0.60

Abbreviation: Condition 1 = Baseline (D1); Conditions 2-5 = Concurrent Condition with Increasing Difficulty(D2 - D5). On Trial 1 Value Inside Paretheses is for Transformed Data.

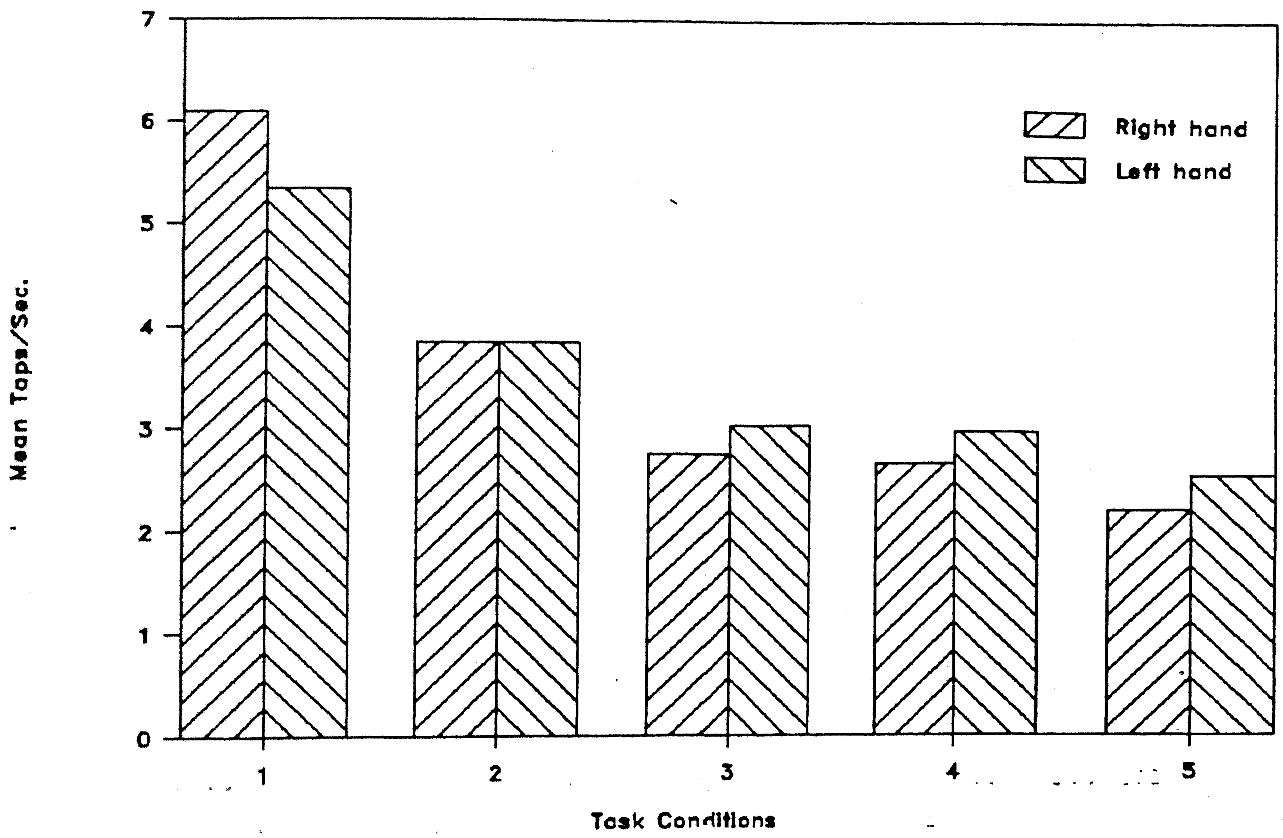

Figure 2.1: Average Performance (Taps/Sec.) of Left and Right Hands as a Function of Difficulty Levels of Task Conditions for Experiment 1A. Under Condition (1) Data were not Transformed Whereas Under Conditions (2-5) Data were Transformed.

conditions (see Table 2.3 & Figure 2.2).

The main effect of sex turned out to be nonsignificant (Table 2.1 & 2.2), therefore H3 stands unsubstantiated. Other three main effects of hand ($F = 16.21$, $df = 1,18$, $p < 0.1$), practice trials ($F = 6.27$; $df = 3, 54$, $p < 0.01$), and task conditions ($F = 156.39$, $df = 4,72$, $p < 0.01$) were found significant. The main effect of hand might be due to progressively more difficult requirement of rule to be followed to carry out the increasingly difficult concurrent tasks over conditions D2 - D5 . As decomposition of task conditions x hand interaction had shown, sequences D3 - D5 were responsible for such results, thus supporting H1 and H2. The effect of practice trials were observed on different task conditions because with increased familiarization, different task conditions showed lesser and lesser generalized interference. The effect of task conditions was noticed because of differential processing demand of concurrent task conditions D2 - D5 on the left and right hand tapping as the difficulty level of tasks varied.

Discussion

Results of experiment 1A support the proposed model. Results showed, as noted earlier, that tapping disruption was less in the left hand as compared to the right hand as the task conditions were made progressively more difficult from D2 to D5. With increased difficulty, inherent motor program (rule) involved in these sequerees also became progressively difficult. Thus, as can be seen from Figure 2.1 and 2.2, there was a visible shift

Table 2.2

Summary of ANOVA for Tapping Data (Experiment 1A)

Source	SS	df	MS	F
Between subject	251.23	19	13.22	
A (Sex)	0.66	1	0.66	0.04
Subject within group	250.56	18	13.92	
Within subject	1198.41	780	1.53	
B (Hand)	6.44	1	6.44	16.21**
C (Familiarization)	11.31	3	3.77	6.27**
D (Task conditions)	883.66	4	220.91	156.39**
A × B	0.041	1	0.041	1.05
A × C	0.180	3	0.060	0.006
A × D	2.92	4	0.73	0.51
B × C	1.54	3	0.51	2.21
B × D	4.38	4	1.09	5.39**
C × D	24.87	12	2.07	7.73**
A × B X C	0.22	3	0.07	0.32
A × B × D	0.58	4	0.14	0.71
A × C X D	2.80	12	0.23	0.87
B × C × D	2.64	12	0.22	1.70
A × B × C × D	2.03	12	0.17	1.31
B × Sub.W.Group	7.15	18	0.397	
C × Sub.W.Group	32.44	54	0.601	
D × Sub.W.Group	101.70	72	1.413	
B × C Sub.W.Group	12.58	54	0.233	
B × D Sub.W.Group	14.64	72	0.023	
C × D Sub.W.Group	57.87	216	0.290	
B × C × D Sub.W.Group	27.95	216	0.129	
al	1449.64	799	1.41	

** = P < .01

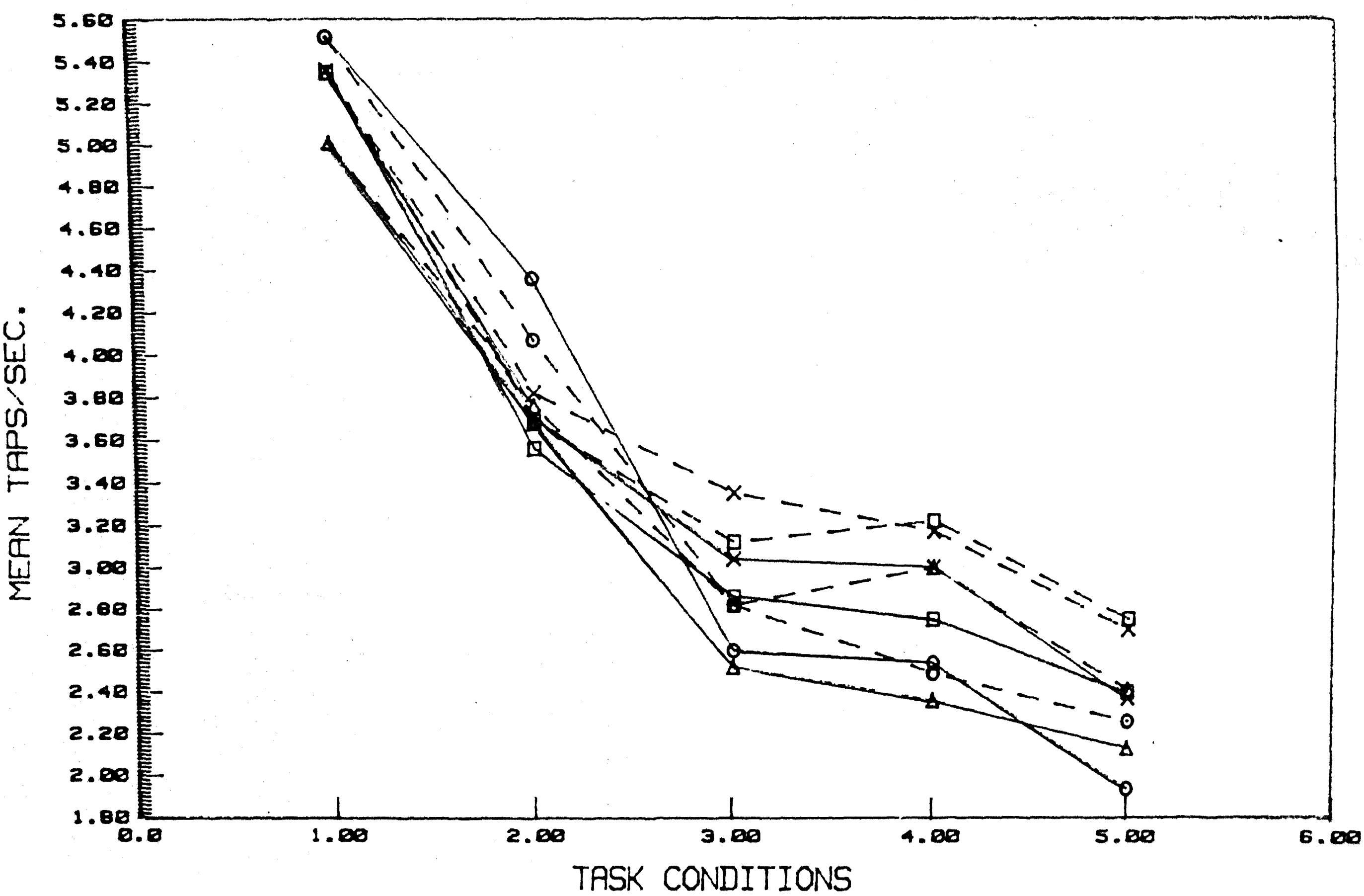

Figure 2.2: Changes in Unimanual Finger Tapping Performance (Taps/Sec.) of Left and Right Hands as a Function of Practice Trials for Experiment 1A. Abbreviation: Circle = Trial 1, Triangle = Trial 2, Cross = Trial 3, and Square = Trial 4. Broken Lines Represent Left-Hand Tapping and Solid Lines Represent Right-Hand Tapping.

Table 2.3

Summary of Simple-Simple Effect Analysis for Tapping Data (Experiment 1A)

	Source	SS	df	MS	F
	Within Subjects				
.	Between B at D1	0.00	1	0.00	
.	B at D2	0.00004	1	0.00004	0.00016
.	B at D3	2.76	1	2.76	11.44**
.	B at D4	3.80	1	3.80	15.75**
.	B at D5	4.18	1,18	4.18	17.33**
	ERROR TERM 0.2412				
.	Between D at B1	449.97	4	112.49	139.47**
.	D at B2	338.84	4	97.21	120.53**
	ERROR TERM 0.8065				
.	Between C at D1	5.57	3	1.85	6.03**
.	C at D2	8.71	3	2.90	9.45**
0.	C at D3	7.65	3	2.55	8.31**
1.	C at D4	8.34	3	2.78	9.06
2.	C at D5	5.91	3	1.97	6.42**
	ERROR TERM 0.3066				
3.	Between D at C1	326.66	4	81.66	154.65**
4.	D at C2	198.49	4	49.62	93.47**
5.	D at C3	190.12	4	47.53	90.01**
6.	D at C4	193.38	4	48.35	91.57**
	ERROR TERM 0.528				

Abbreviation:
** = $p < 0.01$
* = $p < 0.05$
A = Sex
B = Hand
C = Practice Trials
D = Task Conditions

from bilaterlism and generalized processing under task condition D2 to lateralization and specialized processing under task conditions D3 - D5. Hence, it seems logical to conclude that postulation of "generalized processor", and "specialized processor" in the proposed model is a good working hypothesis. This is supported by the observation that low level task D2 showed bilateral processing despite having highest amount of muscle-repositioning, whereas high level tasks D3-D5 where progressively complex rules were involved, showed lateralized processing, suggesting possibility of asymmetrical processing by LH processors on these sequences. In fact, several authors have over the years held the "whole brain", or "interactive hemisphere" notion (Goldberg and Costa, 1981; Levey and Trevarthen, 1976; Luria, 1973, Santhakumari and Sharma, 1990 etc.), but they did not formulate any comprehensive thesis about the parameters under which generalized and lateralized processing would be observed, which is explicitly shown in the proposed model. As noted in the previous chapter, there is ample data to show that both hemispheres of brain are involved in the processing of information, albeit in slightly different patterns (e.g. Lechevalier et. al. 1989). Additional support for this kind of thesis is reported by Wiegersma and Wijnmaalen (1991). They found that right hand tapping was not disrupted more than the left hand tapping by automatic verbal production but it did when controlled verbal production was required. The results of their experiment also showed generalized interference while carrying out automated verbal production. Thus, it seems plausible to conclude that

because automated verbal production is low - level task, generalized interference was observed. Since controlled verbal production is high-level task and requires processing by specialized processors of LH, this would lead to lateralized interference in right hand tapping. As can be seen from Figure 2.2, there was increased interference in right hand performance with increased difficulty of task conditions and such interference was highest on trial 1 of this experiment. But one of the results of Experiment 1A is not in conformity with a priori prediction of the model. As can be noted from Figure 2.2, deterioration in performance was observed on task condition D2 with increased familiarization. But a prior prediction of model would have been that on D2 task condition increased familizattion would not have any effect on the performance because D2 is low level task. Such result could have obtained because increased familization might have produced fatigue, thus deterioration in tapping performance.

The other prediction of the model that familiarization would change a high-level task into low - level task, seems to be plausible. As evident from Figure 2.2 performances on D3 - D5 task condition showed marked improvement over the trials. Such result is obtained because increased familization might have reduced the active attentional requirement of high-level task. Had more number of trials been introduced for familiarization, result would have been more striking.

The findings of this experiment also contradict Kimuara's notion of rapid-reposition of musculature as possible source of interference in right hand activity. Condition D2 was having

highest amount of muscle-repositioning (because middle and Index fingers had to be repositioned after each tap), still conditions D3 - D5 showed greater disruption in right hand tapping than the condition D2. The reason for such findings might be relative complexity of rule involved in D3 - D5 conditions as compared to the D2 condition. This result also suggests for the need of rigorous task analysis before making out any statement about hemispheric asymmetry. Thus it appears that LH has no "rapid repositioning centre" of musculature but it seems that LH processors carry out their computation in rule based mode and every sequential motor activity does involve some kind of rule, and therefore, lateralized interference in motor sequences.

Tapping variability was also obtained on different trials across task conditions. Such variability might have resulted due to following reasons: fatigue, feedback on performance, boredom, automation of rule, thus decreased requirement of processing (Koeing, 1990). It is pertinent to point out here that automation of rule and fatigue may counter the effects of each other, therefore effect of familiarization is not as striking as it should have been (Figure 2.2). The effect of fatigue is evident from analysis of tapping pattern in D2 task condition. Therefore, it is suggested here that to obtain a more clear picture about this variable (practice): (i) baseline should be taken only once in future experiments; (ii) familiarization trials should be large in number, and spaced in different experimental sessions to avoid fatigue and boredom; and (iii) a pay-off for speed and accuracy may also be placed in experimental trials.

Another prediction of the present model was monotonic relationship between task difficulty and concurrent disruption in right and left hand tapping. Results lend support to above hypothesis as can be seen from Figure 2.1. As the complexity of motor sequences was increased from D1 - D5, right hand as well as left hand tapping performance showed corresponding disruption though right hand disruption was more than the left hand disruption. Such differential disrucption might result because complex motor programs were carried out by the LH processors whereas motor activity of each hand was carried out by the contralateral hemisphere. It was hypothesized in the proposed model that a complex motor sequence would consist of two components: (i) a motor program of the sequence, and (ii) a motor activity per se of the sequence.

Experiment - 1B

Studies using simultaneous verbal and manual tasks have shown asymmetric effects in manual task performance (Kinsbourne and Hiscock, 1983). Traditionally, in dichotic listening paradigm a REA is reported for words, nonsensesallabels, backward speech, and syntactic syllables (Kimura and Fold, 1968; Shankweiler and Student - Kennedy, 1967). Such findings are also reported from visual half field method and dual task paradigm (Hicks et al. 1978). Some of these findings are contrary to predictions of the proposed model. For instance, mere articulations of

nonsensesyllabeles would be viewed in the proposed model as low level task, therefore, it should not produce lateralized interference. But as noted above, in the initial period of research in area of hemispheric asymmetry such results had been reported. These findings are suspected on the ground that detailed analysis of task was not carried out. Moreover, dichotic listening technique has suspected validity against attentional tradeoffs, as noted in Chapter I. For example, laterlized interference in right hand tapping has been reported for paragraph reading. But a detailed analysis of paragraph showed that it is not clear whether such lateralization is observed because of verbal articulation of paragraph, or because of semantic content of paragraph, or because of imagery content of paragraph etc. Thus, an interesting question is about the type or nature of verbal processes which are responsible for the interference.

The proposed model makes a priori prediction that low-level task would not show lateralization. To test the above prediction and to contradict the earlier findings that articulation of nonsensesyllebles produces lateralized REA, in experiment 1B, subjects were required to articulate the letters they were tapping. It was hypothesized that articulation of nonmeaningful letters will not change the lateralization pattern observed in experiment 1A.

The traditional view of hemispheric lateralization would hold that articulation of tapped letters (for example 'VN') is an additional load to LH, therefore it would produce lateralized

interference in right hand tapping. Conversely, the proposed model suggests that mere verbalization of letters would not change the pattern of lateralization observed on sequences D3 to D5 because such articulation is an additional low-level task, which may not increase the processing load of specialized processors. On the contrary, such articulation might have generalized interference with D2 sequence or it would change the pattern of generalized interference with D2 sequence because verbalization would be an additional low level task for generalized processor. In view of aforesaid logic following specific hypothesis was formulated.

H_4: Articulation of letters of the tapping sequence does not change the pattern of lateralization on D3 - D5 task condition. But such articulation has a generalized effect on task condition D2 when compared with performance on baseline trial.

Method

There was some variation in the method followed in Experiment 1B as compared to Experiment 1A. In this experiment a new set of 20 subjects (10 males and 10 females) in the age range 18-30 years did the first trial in the same way as they had done in experiment 1A. The purpose of this trial was to establish a baseline performance without articulation of letters of the tapping sequences. On the next three trials, they were asked to say aloud the letter sequence they were tapping. For example, if

they were tapping sequence 'VNNVVN', than they were asked to say it aloud. Apart from this minor variation, everything else was same as in Experiment 1A.

Results

Appendix 1 (A2) contains mean Taps/second for males and females under all the tapping conditions for NT-data. A four-way repeated measures ANOVA (sex x hand x trials x task conditions) was performed on NT-data. Appendix 3 presents a summary of the ANOVA for these data and Appendix 3A contains the simple-simple analysis as well as interaction analysis for the NT-data.

A three-way interaction among hand, practice trial, and task condition was present in NT-data ($F = 4.67$, $df = 12, 216$, $p < 0.01$). In order to understand the nature of this complex interaction, simple interaction analysis as well as simple- simple analysis were carried out. It is clear from the results presented in Appendix 3A that simple interaction is significant for hand x task condition and for practice trial x task condition. Decomposition of data revealed that right hand was more efficient than left hand under the D1 condition as well as D2 condition but on other conditions there was no difference. Since right hand advantage was present under the baseline condition and NT-data is usually insensitive to lateralization effect (Willis and Godwin, 1987), data were transformed as per procedure described in Experiment 1A.

Table 2.4 presents the mean Taps/second and standard deviation for males and females under different task conditions. Figure 2.3 presents the average performance of each hand as a

Table 2.4

Mean Taps/Second and Standard Deviation for Baseline (1) and Concurrent Conditions (2-5) for Males and Females (Experiment 1B)

Conditions		Males		Females	
		Right Hand	Left Hand	Right Hand	Left Hand
1.	Mead	4.80 (4.26)	4.80(4.26)	5.19(4.51)	5.19(4.51)
	S.D.	0.91 (0.48)	0.91(0.48)	0.93(0.77)	0.93(0.77)
2.	Mean	4.04 (3.29)	3.69(3.61)	3.93(3.22)	3.95(3.53)
	S.D.	2.20 (0.77)	0.92(0.64)	0.78(0.83)	0.84(0.60)
3.	Mean	2.33 (2.86)	2.92(3.22)	2.89(2.83)	3.12(3.10
	S.D.	0.50 (0.89	0.64(0.79)	0.82(0.68)	0.53(0.44)
4.	Mean	2.66 (2.64)	2.63(3.21)	2.52(2.47)	2.57(3.04)
	S.D.	0.69 (0.92)	0.68(0.81)	0.77(0.59)	0.60(0.48)
5.	Mean	1.71 (2.04)	2.17(2.28)	2.02(2.19)	2.30(2.44)
	S.D.	0.50 (0.58)	0.61(0.51)	0.71(0.57)	0.65(0.48)

Abbreviation: Condition 1 = Baseline (D1)
Conditions(2-5) = Concurrent Conditions with Increasing Difficulty (D2 - D5)

Mean and S.D. Outside Parantheses is for One Trial Without Verbalization of Tapping Sequence.

Meand and S.D. Inside Parantheses is for Three Trials With Verbalization of Tapping Sequence.

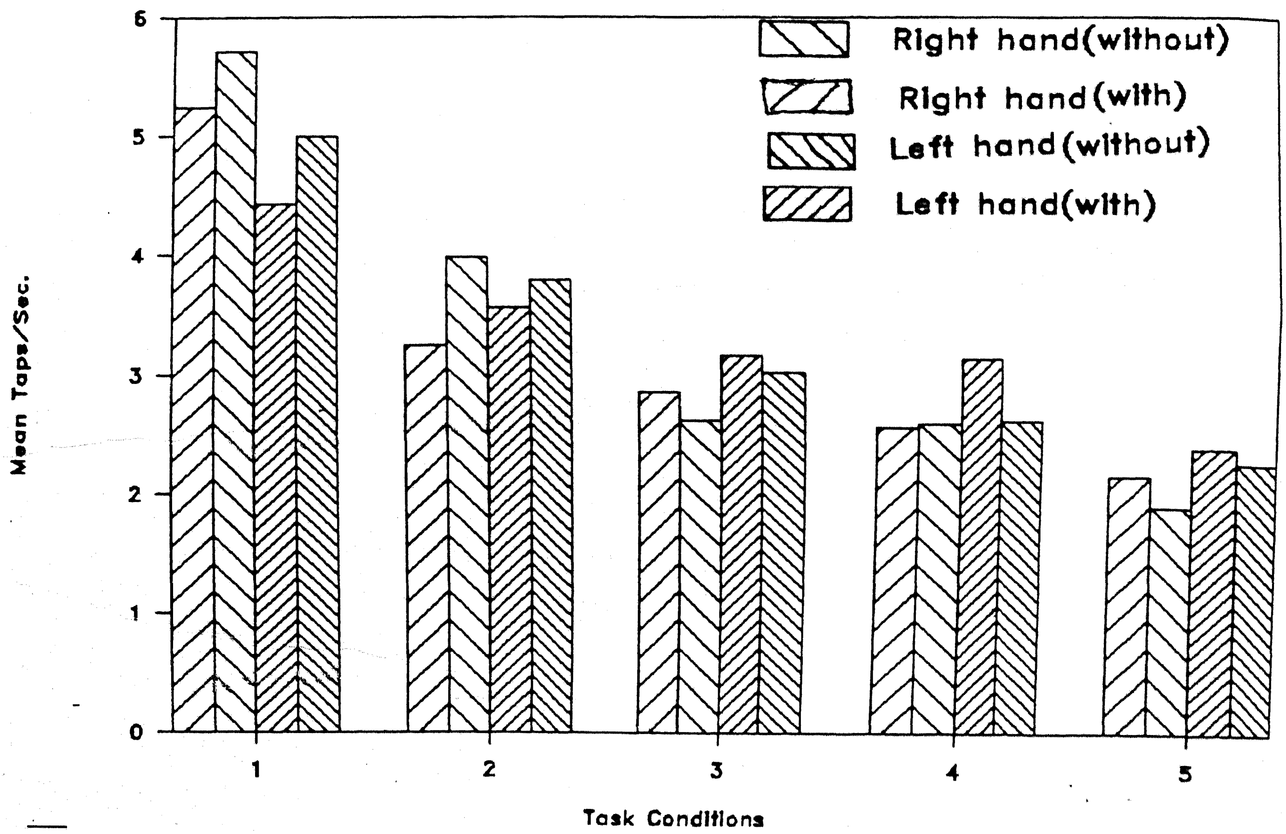

Figure 2.3: Average Performance (Taps/Sec.) of Left and Right Hands as a Function of Difficulty Levels of Task Conditions with Requirement of Articulation of Task Conditions on Last Three Trials and without Requirement of Articulation on First Trial for Experiment 1B.

function of the task difficulty.

ANOVA on T-data revealed a three-way interaction between hand x practice trials x task conditions ($F = 4.50$, $df = 12, 214$; $p < 0.01$). To understand the nature of this complex interaction and to get deeper insight into data simple interaction analysis as well as simple-simple analysis were performed (Table 2.4). As can be seen from the table simple interaction is significant for hand x task conditions ($F = 8.43$, $df = 1,18$, $p < 0.01$) and practice trial x task condition ($F = 3.30$ $df = 3, 216$, $p < 0.01$). Further decomposition of hand x task conditions interaction showed that left hand tapping performance was better than the right hand tapping performance on D2 - D5 task conditions. Thus, it can be concluded that there was lateralized interference in right hand tapping under D2 - D5 conditions. Moreover, right hand performance under the four concurrent task conditions (D2 - D5) differed significantly ($F = 75.24$, $df = 4, 72$, $p < 0.01$) and so did the left hand performance ($F = 55.88$, $df = 4, 72$; $p < 0.01$). Similarly, decomposition of trial x task conditions data showed significant difference amongst task conditions on all the trials (Table 2.6). Further, effect of practice trials was found to be significant for D1 and D2 task conditions only. Results of simple-simple ANOVA presented in Table 2.6 suggests the following: (i) There was significant difference between performance of right hand and left hand (a) on third and fourth trials under D2 condition; (b) on all trials of D3 condition except second trial; (c) first trial of D5 condition, and (d) all trials of D4 condition except first trial (Figure 2.4). (ii) The

Table 2.5

Summary of ANOVA for Tapping Data (Experiment 1B)

	Source	SS	df	MS	F
1.	Between subject	196.60	19	10.34	
2.	A (Sex)	0.43	1	0.43	0.04
3.	Subject within group	196.17	18	10.89	
4.	Within subject	764.04	780	0.98	
5.	B (Hand)	12.36	1	12.36	30.42**
6.	C (Familiarization)	1.75	3	0.58	1.22
7.	D (Task conditions)	520.37	4	130.09	113.91**
8.	A x B	0.02	1	0.02	0.06
9.	A x C	2.17	3	0.72	0.08
10.	A x D	3.71	4	0.92	0.81
11.	B x C	1.10	3	0.37	2.06
12.	B x D	4.23	4	1.05	8.43**
13.	C x D	20.24	12	1.68	8.38**
14.	A x B x C	0.07	3	0.02	0.14
15.	A x B x D	0.31	4	0.07	0.63
16.	A x C x D	1.15	12	0.09	0.47
17.	B x C x D	3.57	12	0.29	4.50**
18.	A x B x C x D	0.70	12	0.05	0.88
19.	B x Sub.W.Group	7.31	18	0.40	
20.	C x Sub.W.Group	25.82	54	0.47	
21.	D x Sub.W.Group	82.22	72	1.14	
22.	B x C Sub.W.Group	9.68	54	0.17	
23.	B x D Sub.W.Group	9.03		0.12	
24.	C x D Sub.W.Group	43.89	216	0.20	
25.	B x C x D Sub.W.Group	14.27	216	0.06	
Total		960.65	799	1.20	

** = P < .01

Table 2.6

Summary of Simple-Simple Effects and Interaction effects analysis for Tapping Data (Experiment 1B)

Source	SS	df	MS	F
B at CD11	0.00	1	-	0.00
B at CD21	0.00	1	-	0.00
B at CD31	0.00	1	-	0.00
B at CD41	0.00	1	-	0.00
B at CD12	0.27	1	-	1.22
B at CD22	0.78	1	-	3.54
B at CD32	1.36	1	-	6.18*
B at CD42	1.02	1	-	4.63*
B at CD13	1.68	1	-	7.63*
B at CD23	0.55	1	-	2.50
B at CD33	1.15	1	-	5.22*
B at CD43	1.29	1	-	5.86*
B at CD14	0.02	1	-	0.09
B at CD24	4.03	1	-	18.31**
B at CD34	3.72	1	-	16.90**
B at CD44	2.16	1	-	9.81**
B at CD15	1.33	1	-	6.04*
B at CD25	0.28	1	-	1.27
B at CD35	0.84	1	-	3.81
B at CD45	0.81	1	-	3.68
ERROR TERM 0.220				
C at BD11	4.68	3	1.56	4.91**
C at BD12	8.14	3	2.71	8.53**
C at BD13	1.08	3	0.36	1.13
C at BD14	0.29	3	0.09	0.28
C at BD15	0.95	3	0.31	0.97
C at BD21	4.68	3	1.56	4.911**
C at BD22	1.02	3	0.34	1.07
C at BD23	1.02	3	0.34	1.07
C at BD24	4.18	3	1.39	4.37**
C at BD25	0.58	3	0.19	0.59
ERROR TERM 0.317				
D at BC11	126.4	4	31.6	72.6**
D at BC12	63.2	4	15.8	36.3**
D at BC13	64.9	4	16.2	37.2**
D at BC14	58.9	4	14.7	33.8**
D at BC21	103.2	4	25.8	59.3**
D at BC22	49.0	4	12.2	28.1**
D at BC23	45.7	4	11.4	26.2**
D at BC24	42.66	4	18.6	24.5**
ERROR TERM 0.435				

Source	SS	df	MS	F
BC at D1	0.0	4	0.0	0.0
BC at D2	1.90	4	0.47	2.76*
BC at D3	0.14	4	0.03	0.17
BC at D4	2.54	4	0.63	3.70*
BC at D5	0.20	4	0.05	0.29
ERROR TERM 0.17				
BD at C1	2.28	3	0.76	6.33**
BD at C2	2.16	3	0.72	6.0**
BD at C3	1.62	3	0.54	4.50*
BD at C4	1.37	3	0.45	3.75*
ERROR TERM 0.12				
CD at B1	12.72	1	-	63.60**
CD at B2	10.77	1	-	53.85**
ERROR TERM 0.20				
B at D1	0.0	1	-	0.0
B at D2	1.59	1	-	7.22*
B at D3	4.54	1	-	20.63**
B at D4	7.39	1	-	33.59**
B at D5	3.06	1	-	13.90
ERROR TERM 0.22				
D at B1	301.0	4	75.2	
D at B2	223.5	4	55.8	221.7**
ERROR TERM 0.25				
C at D1	9.38	3	3.12	9.82**
C at D2	7.29	3	2.43	7.65**
C at D3	1.95	3	0.65	2.04
C at D4	1.99	3	0.66	2.07
C at D5	1.36	3	0.45	1.41
ERROR TERM 0.317				
D at C1	221.1	4	55.2	127.1**
D at C2	110.0	4	27.5	63.2**
D at C3	109.0	4	27.2	62.6**
D at C4	100.2	4	25.06	57.6**
ERROR TERM 0.435				
C at B1	2.35	3	0.78	2.73
C at B2	0.55	3	0.18	0.63
ERROR TERM 0.285				
B at C1	0.78	1	-	3.18*
B at C2	3.51	1	-	14.32**
B at C3	5.18	1	-	21.1**
B at C4	4.08	1	-	16.65**
ERROR TERM 0.245				
B x C	1.10	3	0.37	2.60
B x D	4.23	4	1.05	8.43**
C x D	20.24	12	1.68	3.30

Abbreviation: ** = $p < 0.01$; * = $p < 0.05$
A = Sex; B = Hand
C = Practice Trials; D = Task Conditions

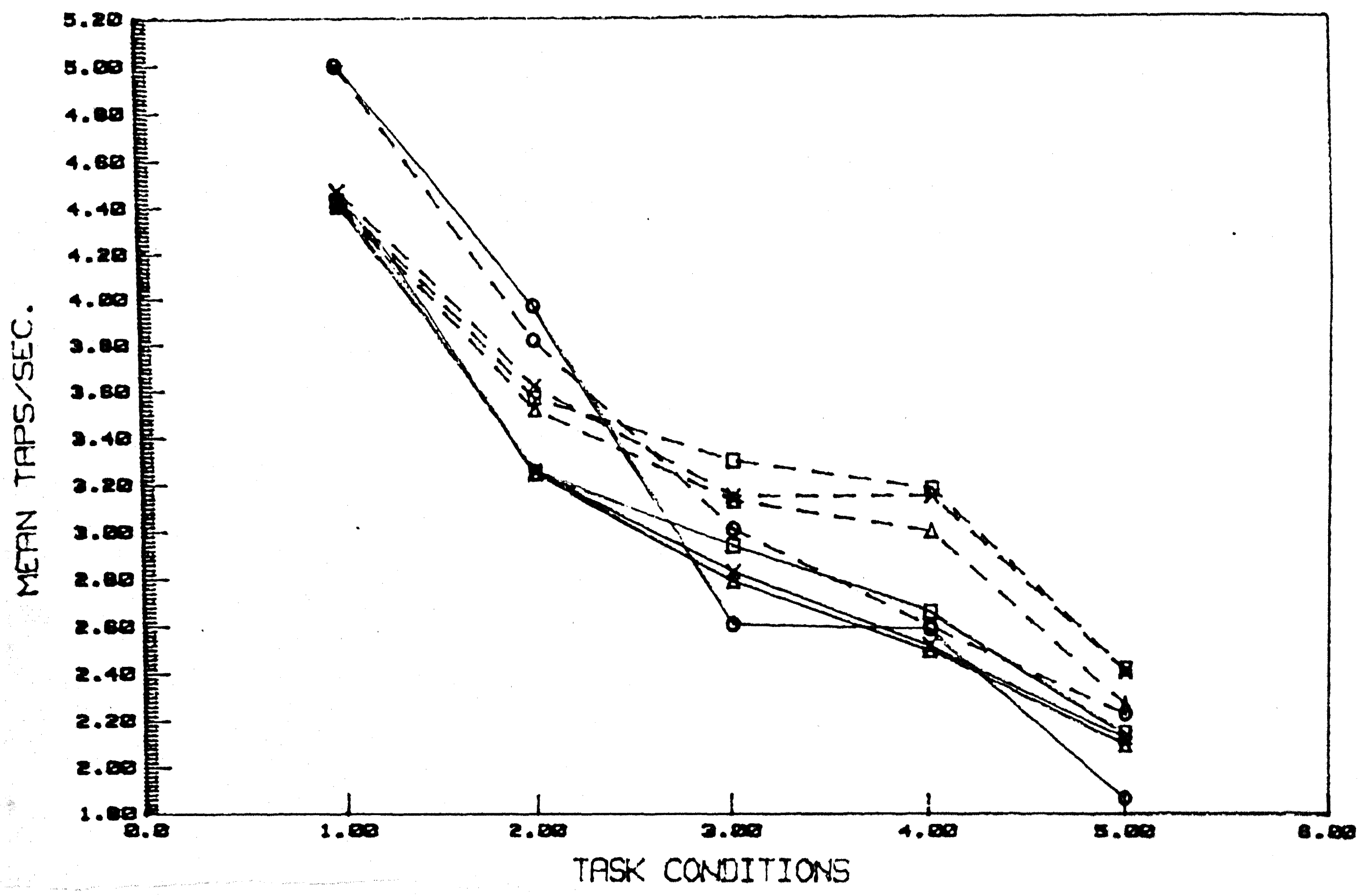

Figure 2.4: Changes in Unimanual Finger Tapping Performance (Taps/Sec.) for the Left and Right Hands as a Function of Practice Trials for Experiment 1B. Abbreviation: Circle = Trial 1, Triangle = Trial 2, Cross = Trial 3, and Square = Trial 4. Broken Lines Represent Left-Hand Tapping and Solid Lines Represent Right-Hand Tapping.

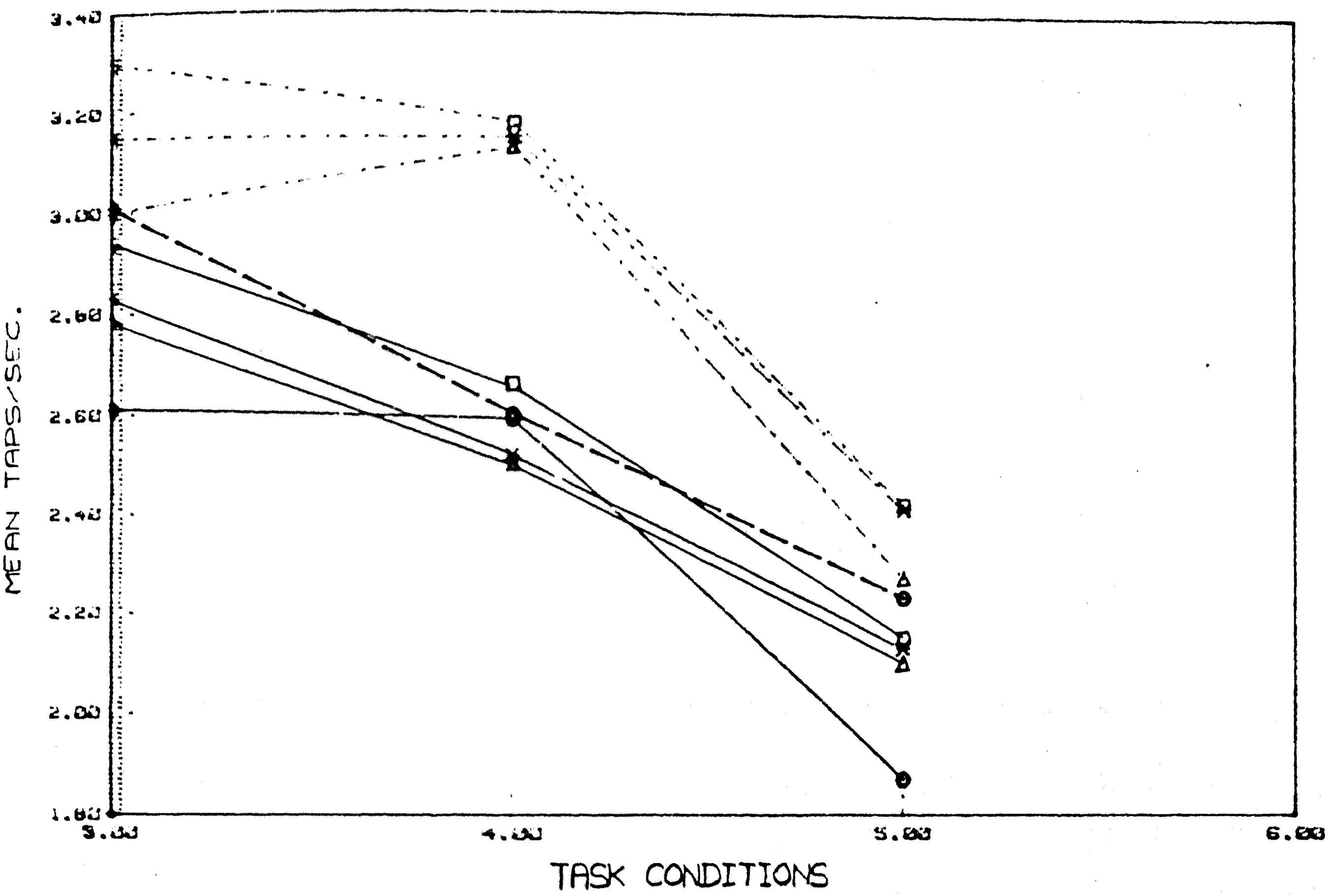

Figure 2.4A: A Magnified View of D3-D5 Task Condition for Experiment 2B..

effect of practice trials was significant for D1 and D2 task conditions for right hand and D1 and D4 task conditions for left hand; and (iii) The effect of Task difficulty was significant for right as well as left hand across all the trials i.e. more difficult the task condition, more was tapping disruption in both hands.

Main effect of hand ($F = 30.42$, $df = 1, 18$, $p < 0.01$) and task conditions ($F = 113.91$, $df = 4, 72$, $p < 0.01$) was found significant. Main effects of sex and practice trials turned out to be nonsignificant (Table 2.5).

Discussion

Experiment 1B was designed to test the hypothesis that mere articulation of tapping letters would not change the pattern of lateralization over and above the pattern of lateralization obtained without the articulation of tapping letters. The results of Experiment 1B cast doubt on the postulation of "generalized processor" in the proposed model. The prediction of the model, that only generalized interference would be observed under D2 Task condition (low-level task), stands unsubstantiated as results of Experiment 1B show lateralized interference under D2 task condition also. But, a close scrutiny of results of experiment 1B suggest that above results are quite weak to refute the postulation on these accounts:(i) Results were significant only at $p < 0.05$ level which is quite weak considering all other results in all the experiments which were significant at $p < 0.01$ level. (ii) There was significant disruption in performance on

introduction of articulation for both right and left hand under D2 task condition (Figure 2.4), reversal of this trend is not observed on next three trials which should have been the case had lateralization pattern of D2 been similar to D3 - D5. (iii) There could be a possibility that owing to capacity limitation of generalized processor being used by D2 sequence without articulation, the processing of additional low-level task (e.g., articulation of 'VN' sequences) might be carried out by the specialized processors of LH in situation of resource limitation.

Barring this, there was no change in the pattern of lateralization under D3 - D5 task conditions as can be seen from Figures 2.2 and 2.4. Introduction of verbalization of the letter being tapped did not change the lateralization pattern on last three trials, as compared to the lateralization pattern of first trial. This supports the hypothesis that mere articulation of letters would not be lateralized. Had there been lateralisation, the curves on last three trials should have intersected the curve on the first trial for each hand separately. This is not the case as can be seen from Figure 2.4. Thus, it seems logical to conclude that mere articulation of letters per se will not be lateralized. Additional support to this conclusion may be derived from Wiegersma and Wijnmaalen (1991), who found lateralized interference in right hand tapping for controlled verbal production but no such interference was reported for habitual verbal production.

The results obtained through simple-simple analysis (refer Table 2.6) were quite inconsistent and difficult to explain. Still, by and large findings support the postulates of the model. A reference to Table 2.6 reveals the following: (i) Nowhere except under D2 condition pattern of lateralization did change in comparison with Experiment 1A. (ii) On D5 task condition bilateral processing was carried out after introduction of articulation of sequences on second trial only. This suggested that articulation of sequences did have some positive effect on RH tapping which is consistent with the general premise of the model that performance would imporve with increased familiarization. The plausible reasons for observed lateralized interference on D2 conditions are already noted above and it was concluded that such inconsistency is not of the nature to falsify the predictions of the model.

Experiment 2A

Traditional, concurrent task paradigm was used in Experiment 2A to test the hypothesis that mere reading or articulation of paragraph would not result in lateralization effect. In Experiments 1A and 1B, a successive version of concurrent task paradigm was used. In the successive paradigm, it was hypothesized that a complex motor task would consist of two components: (a) a motor activity component of hands controlled by contralateral hemisphere, and (b) a motor program or rule component supposedly computed in LH. Thus, baseline tapping performance was compared with complex motor task performances. On

the other hand, in Experiments 2A and 2B, a motor task (D1 sequences of first two experiments) and a verbal task was used simultaneously to study the effect of performance of verbal task on motor task.

In past, researchers have reported that LH is dominant for a variety of language tasks, such as production of language (Hicks 1975. Kisbourne & Hiscock, 1983), perception of language (kimura, 1961) etc. Bowers et al. (1978) reported that studying paragraph impairs right hand performance and such interference is lateralized. But such findings instead of shedding light on nature of hemispheric asymmetry, complicates the matter. The reason for such complication is that a paragraph is made of a number of linguistic components like semantic component of paragraph, particular kind of syntactic form of paragraph, imagery content of paragraph or prosody of paragraph etc. It is not clear from the reported findings as to which of the many components is responsible for hemispheric asymmetry. Thus, in the present experiment an attempt was made to investigate the effect of reading of paragraph on concurrent unimanual tapping. To ward against the possibility of confounding, subjects were specifically told before the commencement of experiment that how early they finished reading the paragraph was only important from the point of view of study. They were also requested not to pay attention to the content of paragraph while doing the tapping task and reading the paragraph. Still, to avoid the possibility of unconscious/deliberate comprehension of paragraph, subjects were asked certain questions related to comprehension of paragraph at

the end of the Experimental session. The emphasis of the present experiment was at micro level of task as the central interest was specifically to see whether language articulation produces lateralized interference or not. Green et. al (1990) have advocated the use of multi-task method to assess the hemispheric lateraliztion. Thus use of language articulation and language comprehension in Experiments 2A and 2B was in coherence with their recommendation. The same might be said about the motor tasks used in Experiments 1A and 1B to test the predictions of the proposed model.

It was hypothesized that language articulation or mere reading of paragraph would not have lateralized effect as reading of text is a highly familiar activity, thus a low-level task. But it may have a generalized effect on the tapping performance.

Method

Experimental Design: A 2 x (Sex: Male, female) 2 x (Hand: right and left hand tapping) 4 x (Trials) 2 (Task condition: Baseline and concurrent task conditions) factorial design with repeated measures on last three factors was used.

Subject: Ten males and ten females, drawn from the undergraduate and Post graduate classes of IIT Kanpur in age range of 18 to 30 yrs participated in the study. All subjects were self declared right handers.

Instrumentation: The motor task involved simple repetitive tapping of key 'V' of a personal computer. The tapping rate was computed by the program as described in Experiment 1A.

Stimulus material: Subjects were required to read a paragraph of Burtrand Russell pertaining to "value of philosophy" (Appendix 6) as concurrent verbal task.

Procedure: As individual differences in reading speed were expected, performance under concurrent task condition was obtained first. Under this condition, the subjects was explicitly asked to carry out the reading of the paragraph as fast as possible. He was also told that how quickly he finished reading the paragraph was only important from the point of view of the experiment. He was instructed to read the given paragraph as fast as possible without paying attention to the content of the paragraph. The task continued with a given hand till the entire paragraph was read. This constituted a trial. On an average one trial took about 80 sec.The same procedure was repeated for four trials with each hand with counter balancing of hands. The same paragraph was used in each trial in order to investigate the effect of familiarization.

The time taken to finish reading the paragraph was recorded for each hand and trial separately . As next step the subject was asked to do simple finger tapping task for the same duration of time as taken under the concurrent task condition. To ward against the possibility of attention being paid to content of paragraph, post hoc questions were asked related to content of paragraph; e.g. the subject was asked to give the gist of the paragraph. Only one subject was able to produce the gist and he was replaced by a new subject as he was not carrying the task as per instructions.

Analysis of reading time was also carried out to eliminate the above possibility. It was assumed on the basis of a pilot study that if subjects did not pay attention to the meaning of passage and took the reading task as mere articulation task then there would be only slight variation in the reading time across four trials. On the basis of pilot study on three individuals a variation of about 15 seconds was observed over trials. The variability in paragraph reading time across trials observed in this experiment was below this limit of 15 seconds.

Results

Appendix 1 (A3) contains mean Taps/second for males and females on baseline and concurrent task condition for NT-data. A four-way repeated measures ANOVA (sex x hand x practice trials x task conditions) was performed on NT-data. Appendix 4 present the summary of ANOVA for this data and Appendix 4A provides the simple-simple analysis as well as interaction analysis for NT-data.

A three-way interaction among hand, practice trial and task condition was present in the data ($F = 3.45$, $df = 3,54$; $p < 0.01$). Further, decomposition of data showed presence of interaction for hand x task condition and trials x task conditions (appendix 4A). Decomposition of hand x task conditions interaction showed that right hand tapping was superior to left hand tapping on baseline and concurrent conditions. Because right hand advantage was present at baseline tapping, data were transformed as per procedure described in Experiment 1A.

Table 2.7

Mean Taps/Second and Standard Deviation for Base line (1) in Concurrent Task Condition (2) for Males and Females (Experiment 2A)

Conditions		Males		Females	
		Right Hand	Left Hand	Right Hand	Left Hand
1.	Mean	5.58(4.60)	4.60	5.38(4.42)	4.42
	S.D.	0.52(0.59)	0.59	0.49(0.63)	0.63
2.	Mean	4.29	4.38	4.24	4.27
	S.D.	0.60	0.51	0.72	0.57

Abbreviation: Condition 1 = Baseline (D1)
Condition 2 = Concurrent Tapping (D2)
Under Baseline Conditions Value Inside Parentheses is for Transformed Data

Table 2.8

Summary of ANOVA for Tapping Data (Experiment 1A)

	Source	SS	df	MS	F
1.	Between subject	100.17	19	5.27	
2.	A (Sex)	1.33	1	1.33	0.24
3.	Subject within group	98.84	18	5.49	
4.	Within subject	13.83	300	0.04	
5.	B (Hand)	0.06	1	0.06	2.30
6.	C (Familiarization)	0.27	3	0.09	2.09
7.	D (Task conditions)	3.83	1	3.83	17.97**
8.	A × B	0.02	1	0.02	0.82
9.	A × C	0.05	3	0.01	0.02
10.	A × D	0.23	1	0.23	1.08
11.	B × C	0.04	3	0.01	2.19
12.	B × D	0.06	1	0.06	2.40
13.	C × D	0.79	3	0.26	32.46**
14.	A × B × C	0.017	3	0.006	0.92
15.	A × B × D	0.017	1	0.017	0.59
16.	A × C × D	0.021	3	0.007	0.88
17.	B × C × D	0.04	3	0.014	2.28
18.	A × B × C × D	0.020	3	0.007	1.06
19.	B × Sub.W.Group	0.50	18	0.028	
20.	C × Sub.W.Group	2.38	54	0.044	
21.	D × Sub.W.Group	3.84	18	0.213	
22.	B × C Sub.W.Group	0.333	54	0.006	
23.	B × D Sub.W.Group	0.504	18	0.028	
24.	C × D Sub.W.Group	0.438	54	0.008	
25.	B × C × D Sub.W.Group	0.332	54	0.006	
Total		114.00	319	0.357	

** = P < .01

Table 2.9

Summary of Simple-Simple Effect Analysis for Tapping Data (Experiment 2A)

	Source	SS	df	MS	F
	Within Subjects				
1.	C at D1	0.33	3	0.11	4.23**
2.	C at D2	0.73	3	0.24	9.23**
3.	D at C1	2.57	1	-	43.37**
4.	D at C2	1.33	1	-	22.44**
5.	D at C3	0.53	1	-	8.94**
6.	..... D at C4	0.18	1	-	3.03

ERROR TERM 0.5925

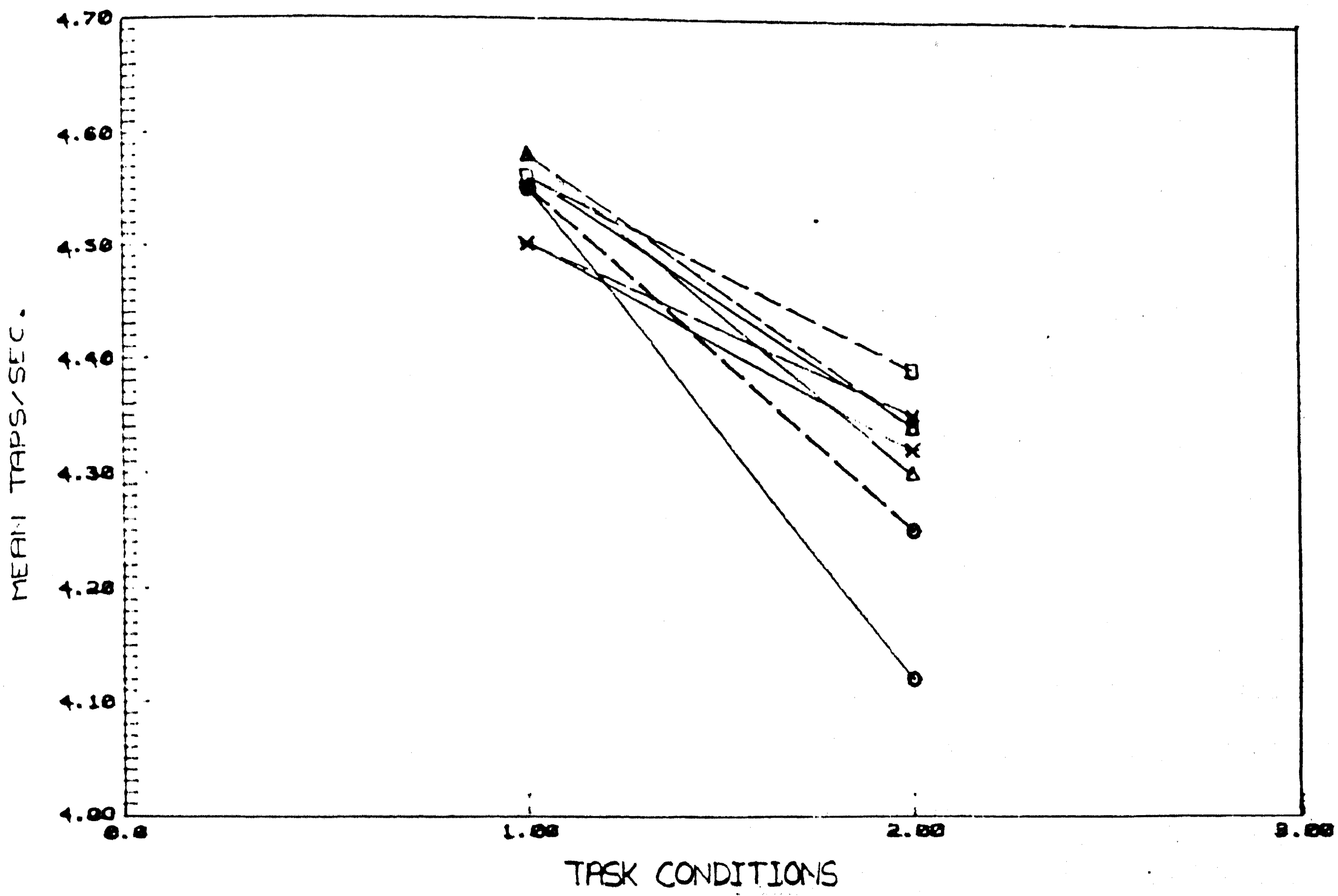

Figure 2.6: Changes in Unimanual Finger Tapping Performance (Taps/Sec.) for the Left and Right Hands as Function of Practice Trials for Experiment 2A. Abbreviation: Circle = Trial 1, Triangle = Trial 2, Cross = Trial 3, and Square = Trial 4. Broken Lines Represent Left-Hand Tapping and Solid Lines Represent Right-Hand Tapping.

Table 2.7 shows the mean taps/second and standard deviation for males and females under baselines and concurrent task conditions on T-data. Figure 2.5 presents the average performance of each hand as a function of task conditions.

ANOVA of T-data showed two way-interaction between trials x task conditions. To get further insight, simple-simple analysis was carried out (Table 2.8 and 2.9). As can be seen from Tables 2.8 and 2.9 the effect of practice was significant for baseline and concurrent task conditions across trials ($F = 4.23$ and 9.23, $df = 3, 54$, $p < 0.01$). Moreover, significant difference between baseline task condition and concurrent task condition was observed on first three trials of experiment, but no such difference was present on the fourth trial. (Refer figure 2.6 and Table 2.9.)

Main effect of task condition turned out to be significant ($F = 17.97$, $df = 1, 18$, $p < 0.01$). This shows the observed generalized effect under concurrent task condition in comparison to baseline task (refer Figure 2.5 and Table 2.8). Main effect of sex, hand, and practice trials were nonsignificant.

Discussion

The results of this experiment support the proposition based on the model that mere reading of paragraph or articulation of any linguistic task, will not have lateralized effect in concurrent task paradigm. As can be seen from Figure 2.5 and Table 2.8, there was no significant difference in performance of right and left hand on concurrent task condition, though a generalized interference was clearly visible in the performance of both the hands. Thus, the concept of generalized processor stands

substantiated by the results of this experiment because of the presence of generalized interference on a low- level concurrent task. These results are in line with the results of Wiegersma and Wijnmaalen (1991), who also found generalized interference for habitual verbal production and no lateralized interference was observed in their experiments on such tasks for right hand tapping performance.

The results of this experiment also show that in the field of hemispheric asymmetry micro-analysis of task is very important to know the precise task demands for hemispheric asymmetry. For example, previous researchers have shown lateralization for paragraph reading (Bowers et. al, 1978). But results of the present experiment clearly show that such results could have been obtained because of confounding of paragraph reading with extraction of meaning of paragraph or because of paying attention to some other features of the paragraph. However, no such confounding would be present if the subjects are constrained to confine to reading task only.

Experiment 2B

Experiment 2B is a logical next step to Experiment 2A. In Experiment 2A, it was demonstrated that mere articulation (reading) of paragraph has no lateralized interference in the tapping performance of right hand. The reason adduced for such finding was that reading of paragraph is more or less a habitual task, thus, it fits in the category of low-level task in the proposed model. As low-level tasks are carried out by generalized processor, no lateralized interference should be observed. Now

the question is-"What happens when one has to read the paragraph with a view to understanding or comprehending it?" In experiment 2B, this question was tested. It was hypothesized that comprehension of paragraph would lead to hemispheric asymmetry because comprehension of language requires attentional or rule based processing in order to understand the meaning of a texts.

In past, left hemisphere dominance for a variety of language tasks has been reported with respect to speech perception (Molfese, 1980), verbal coding processes (Seaman, 1979; seamon & Gazzaniga, 1973), category matching (Urcuioli, Klein, & Day, 1981), and recognition of consonant-vowel syllables (Springer, 1977). In an excellent review of RH linguistic capacity Sealiman (1977) noted that case for unilateral specialization of linguistic functions seems much more frequently made for production aspects of language than the comprehension aspects (See, Hiscock 1983, also).

Such findings are not in consonance with the general postulates of the model which is stated in terms of high and low level tasks. There is no a priori reason to believe that comprehension task would be low-level task, at least relative to the language production tasks. One possibility for reporting such differences was confounding of language production and comprehension in absence of micro-analysis of tasks in terms of components in earlier experiments. This possibility was demonstrated to be true in Experiment 2A.

Further, tasks like verbal coding, category matching, etc. could be viewed as comprehension tasks because these processes

are always carried out in reference to already comprehended category. Thus, in the present experiment two features of language - articulation of texts and comprehension of text- were tested. The first trial of Experiment 2B was the same as the all trials in Experiment 2A. On this trial subjects were asked to read the paragraph without paying attention to the content of the paragraph. On the next three trials, they were told to read the paragraph with a view to understanding it, so that they would be in a position to answer comprehension questions related to the paragraph at the end of each trial.

Method

Except some minor variation which is noted above the method employed in Experiment 2B was the same as in Experiment 2A. A new set of 20 subjects (10 males and 10 females) participated in this Experiment. The first trial of Experiment 2B was taken to establish a baseline performance without requirement of comprehension in verbal production task. On the next three trial, the subject was required to carry out a verbal production task with a view to comprehending it. Lateralization patterns of these two conditions were compared to know the effect of comprehension on verbal production task as well as sequential finger tapping task.

Results

Appendix 1 (A4) contains mean taps/second for males and females under baseline and concurrent task conditions for NT-data. A four- way repeated measures ANOVA (sex) x (hand) x (practice

Table 2.10

Mean Taps/Second and Standard Deviation for Baseline (1) and Concurrent Condition (2-5) for Males and Females (Experiment 2B)

Conditions		Males		Females	
		Right Hand	Left Hand	Right Hand	Left Hand
1.	Mean	5.10(5.07)	5.10(5.07)	4.79(4.77)	4.79(4.77)
	S.D.	0.57(0.52)	0.57(0.52)	0.71(0.68)	0.71(0.68)
2.	Mean	4.71(4.21)	4.85 (4.63)	4.32(3.90)	4.49(3.97)
	S.D.	0.43(0.75)	4.42(0.70)	0.70(0.69)	0.61(0.59)

Abbrivation: Condition 1 = Baseline (D1)
Condition 2 = Concurrent Condition (D2)
Meand and S.D. Outside Parathense is for One Trail without Requirement of Comprehension.
Mean and S.D. Inside Parathense is for Three Trials with Comprehension.

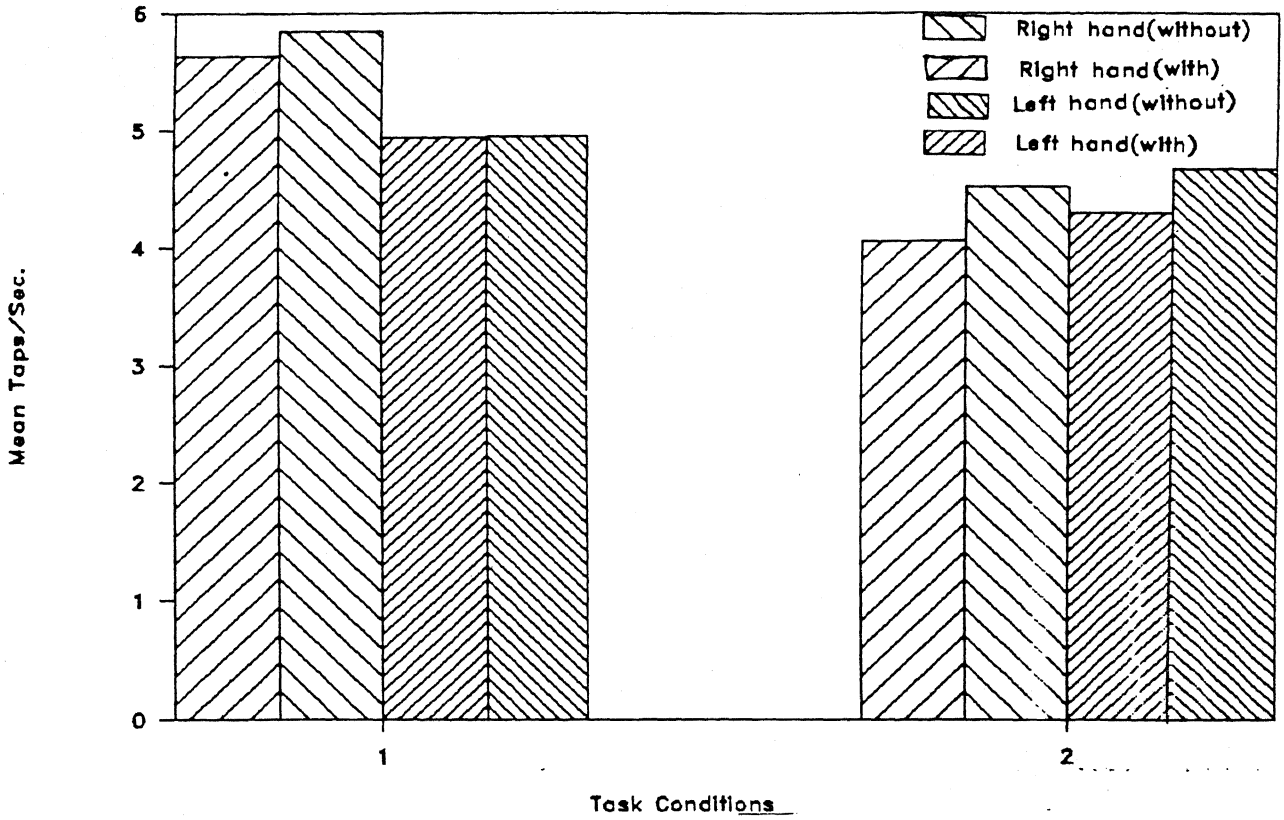

Figure 2.7: Average Performance (Taps/Sec.) of Left and Right Hands as a Function of Verbal Comprehension of Paragraph on Last Three Trials and without Requirement of Verbal Comprehension on First Trial for Experiment 2A.

Table 2.11

Summary of ANOVA for Tapping Data (Experiment 2B)

	Source	SS	df	MS	F
1.	Between subject	118.02	19	6.21	
2.	A (Sex)	9.38	1	9.38	1.55
3.	Subject within group	108.64	18	6.03	
4.	Within subject	58.70	300	0.196	
5.	B (Hand)	0.395	1	0.395	8.21**
6.	C (Familiarization)	3.742	3	1.247	25.96**
7.	D (Task conditions)	37.08	1	37.08	134.40**
8.	A × B	0.041	1	0.041	0.844
9.	A × C	0.159	3	0.053	0.061
10.	A × D	0.133	1	0.133	1.483
11.	B × C	0.045	3	0.015	1.07
12.	B × D	0.392	1	0.392	8.18**
13.	C × D	3.647	3	1.21	31.96
14.	A × B × C	0.044	3	0.015	1.04
15.	A × B × D	0.048	1	0.048	0.999
16.	A × C × D	0.011	3	0.004	0.094
17.	B × C × D	0.047	3	0.016	1.10
18.	A × B × C × D	0.034	3	0.011	0.787
19.	B × Sub.W.Group	0.865	18	0.048	
20.	C × Sub.W.Group	2.594	54	0.048	
21.	D × Sub.W.Group	4.967	18	0.276	
22.	B × C Sub.W.Group	0.763	54	0.014	
23.	B × D Sub.W.Group	0.862	18	0.048	
24.	C × D Sub.W.Group	2.054	54	0.038	
25.	B × C × D Sub.W.Group	0.771	54	0.014	
Total			319		

** = $P < .01$

Table 2.12

Summary of Simple-Simple Effects for Tapping Data (Experiment 2B)

Source	SS	df	MS	F
Within subject				
1. B at D1	0.0	1	-	0.0
2. B at D2	0.78	1	-	16.25**
ERROR TERM 0.048				
3. D at B1	22.56	1	-	139.25**
4. D at B2	14.92	1	-	92.09**
ERROR TERM 0.162				
5. C at D1	0.23	3	0.076	1.76
6. C at D2	7.15	3	2.38	55.34**
ERROR TERM 0.043				
7. D at C1	2.44	1	-	25.02**
8. D at C2	17.79	1	-	182.46**
9. D at C3	11.01	1	-	112.92**
10. D at C4	9.48	1	-	97.23**
ERROR TERM 0.0975				

Abbreviation: ** = P < 0.01
* = p < 0.05
A = Sex
B = Hand
C = Practice Trials
D = Task Conditions

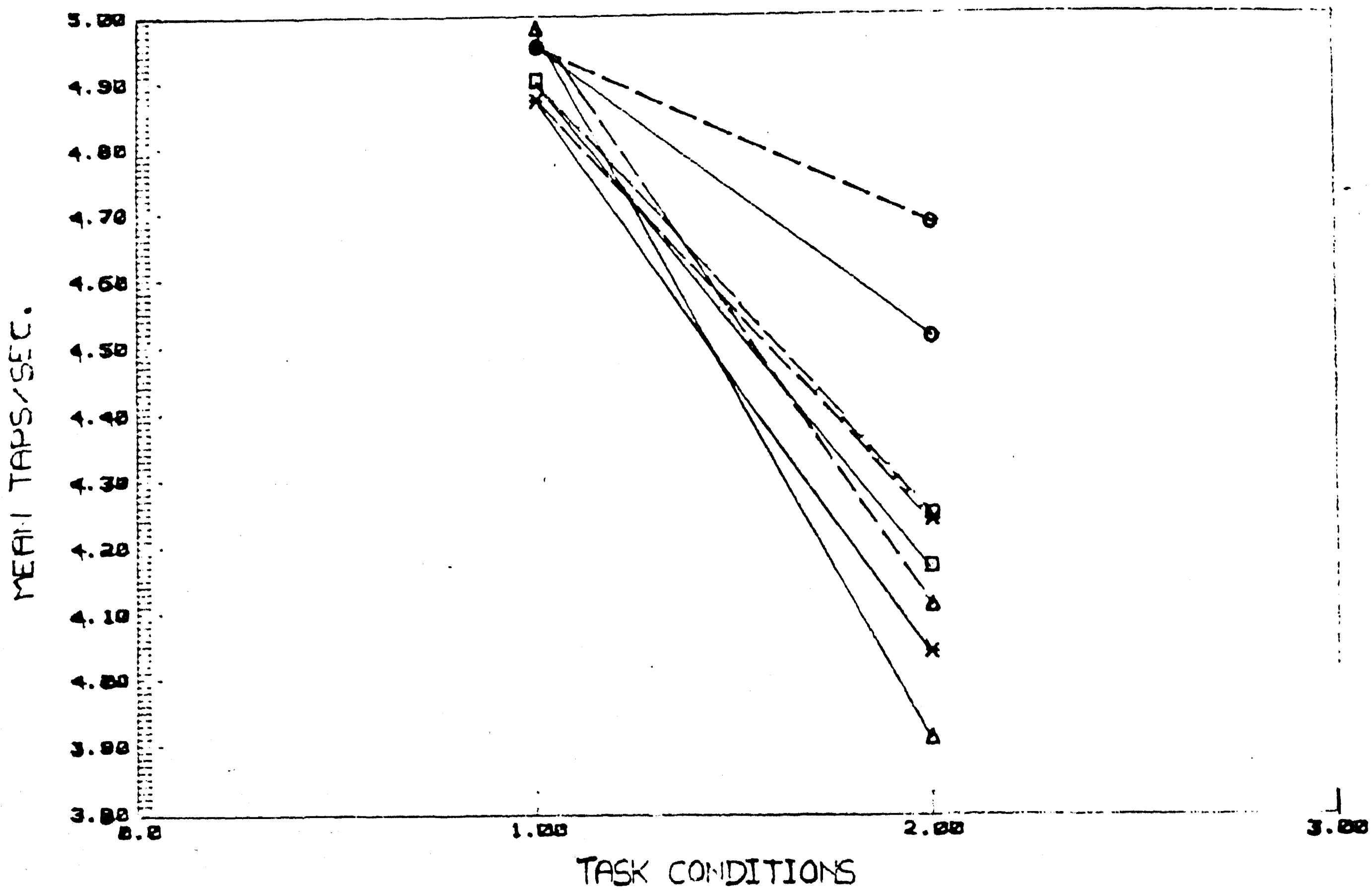

Figure 2.8: Changes in Unimanual Finger Tapping Performance (Taps/Sec.) for the Left and Right Hands as Function of Practice Trials for Experiment 2B. Abbreviation: Circle = Trial 1, Triangle = Trial 2, Cross = Trial 3, and Square = Trial 4. Broken Lines Represent Left-Hand Tapping and Solid Lines Represent Right-Hand Tapping.

trials) x (task conditions) was performed on NT-data. Appendix 5 presents the summary of ANOVA for NT-data and Appendix 5A presents the simple-simple analysis as well as interaction analysis for NT-data.

Three two-way interactions (hand x practice trials; hand x task conditions, and practice trials x task conditions) were found significant in the NT-data (Table Appendix 5A and 5). Further decomposition of data showed that tapping rates of right hand and left hand were different for both the conditions. As right hand advantage was present on the baseline condition, data were transformed as per procedure described in Experiment 1A.

Table 2.10 presents the mean taps/second and standard deviation for males and females under baseline and concurrent task conditions on T-data. Figure 2.7 presents the performance of each hand as a function of task condition.

ANOVA based on T-data showed presence of two-way interactions for hand x task condition and practice trials x task conditions. Decomposition of hand x task condition data revealed that there was a significant difference between performance of right hand and left hand on concurrent task condition ($F = 16.25$, $df = 1,18$, $p < 0.01$). This result showed the lateralized interference in the right hand taping as function of paragraph reading when comprehension of the paragraph was required. Apart from this lateralized interference, generalized interference in both hands were also noted ($F = 139.25$, and 92.09; $df = 1, 18$, $p < 0.01$). Moreover, decomposition of practice trials x task conditions interaction revealed that effect of the practice was

significant for concurrent task only ($F = 55.34$, $df = 3,54$, $p < 0.01$). Significant difference between baseline tapping and concurrent tapping were observed on all the trials.

Main effects of hand, practice trials and task conditions were significant (refer Table 2.11). The main effect of hands showed lateralization interference, main effect of task conditions showed generalized interference and main effect of practice showed improvement in performance of right hand with increased femiliarization.

Discussion

The results of this experiment unequivocally support the prediction of the proposed model. As Figure 2.8 reveals, introduction of requirement of comprehension of paragraph while reading it led to significant disruption in the performance of right hand, suggesting lateralized interference. At this point, it becomes more crystal clear that previous findings for lateralized interference in right hand tapping while reading paragraph, were obtained because of confounding of verbal production and verbal comprehension. Thus, it can be concluded that only controlled verbal production (e.g. verbal production with an aim to understand the paragraphs in Experiment 2B shows lateralization effect because such processes require active attentional and programmed processing of texts. The results of this experiment are supported by the results of Wiegersm and Wijnmaalan's (1991) experiment who also found lateralized interference for controlled verbal production and generalized interference for habitual verbal production.

CHAPTER 3

GENERAL DISCUSSION, SUMMARY, AND CONCLUSIONS

Contents

An Overview

This chapter provides an overall understanding of the phenomenon of hemispheric asymmetry. It aims at integrating the findings of the previous chapter in light of the proposed model, providing a general discussion of results and suggesting various issues which need attention of future researchers.

The chapter has been divided into two parts. The first part deals with the general discussion and conclusions. The second part suggests various issues which need rigorous experimentation in order to improve and crystallize the conception of hemispheric lateralization. It also discusses, perceived limitations of the present work.

The Background

The goals envisaged for the present dissertation as pointed out in Chapter I were the following: (i) to evaluate and integrate the various models of hemispheric lateralization into a more parsimonious model; (ii) to carry out initial testing of the model proposed in the first chapter; (iii) to attempt a reinterpretation of certain experimental results in amore parsimonious way in light of the proposed model; and (iv) to show the importance of micro-analysis of input data and processing capabilities for the precise understanding of the concept.

To meet the above objectives, a thorough and indepth evaluation of the existing models and techniques was carried out. It was noted that models are proposed either in terms of input characteristics, e.g. verbal/spatial hemispheres or spatial frequency of input tasks as determinant of hemispheric

lateralization, or they are proposed in terms of processing capabilities attributed to hemispheres, e.g. analytic/holistic hemispheres or category/coordinate hemispheres. Moreover, it was also observed that none of the models is in the position to account for the entire set of empirical data generated over the years. In view of the above, both input characteristics and processing capabilities attributed to hemispheres are included in the model proposed in the present thesis. Thus, the model presented in the thesis envisaged two kinds of processors, (i) a generalized processor, and (ii) specialized processors. Moreover, it was shown that at low level of task difficulty, generalized processor accomplishes processing bilaterally. Conversely, at high level tasks specialized processors of LH or RH do the processing depending upon input characteristics. If input requires programmed and rule based processing, it is carried out by the LH. Contrarily, if input requires relatively unprogrammed processing as a result of the involvement of uncertainty in the input task, then it is processed by the RH.

To meet the last three objectives, four experiments were carried out. These experiments were designed in such a way that the testing of the predictions of the model becomes feasible. The concurrent task-paradigm was used in all the four experiments. In this paradigm, subjects are required to do one motor and one cognitive task simultaneously. In the first two experiments, instead of using traditional paradigm, an improvised successive version of the concurrent task paradigm was used. In this, a motor task of varying difficulty was used in which the simplest of motor task i.e. simple tapping served as a baseline and more

complex motor sequences served as concurrent task. Disruption in right and left hand tapping was noted on complex motor tasks in comparison to baseline tapping. It was suggested that the reason behind differential disruption in right hand tapping was the involvement of a rule based component in complex motor sequences. In Experiments 2A and 2B the traditional paradigm of concurrent task was used, in which subjects were required to do a habitual verbal production task and a verbal production task with requirement of comprehension along with a simple motor task.

Different groups of ten males and ten females in the age range of 18 to 30 years participated in the experiments. They all were self declared right handers. The data were collected using a personal computer which also did the preliminary analysis of data at the time of data collection itself. Such analyzed data were subjected to 2 (Hand: right, left) x 2 (Sex: male, female) x 4 (Practice trials) x 5 or 2 (Task conditions) ANOVA with repeated measures on all the factors except second.

The results revealed following findings: (1) A lateralized interference was noted in right hand tapping than in the left hand tapping when: (a) subjects did the complex motor sequences D3 - D5 in the Experiment 1A, and D2 - D5 sequences in Experiment 1B; (b) when the subjects were carrying out verbal production task with requirement of comprehension of the verbally produced (reading) material (Experiment 2B). (2) A generalized interference was observed in the right hand tapping as well as in the left hand tapping when subjects were required to do a low-level task i.e. carrying out a simple motor sequence D2 in Experiment 1A, or when they were carrying out habitual verbal production task (reading of

paragraph without requirement of comprehension in experiment 2B. (3) The effect of practice trials was quite complex. Though results of this variable did not substantiate the hypothesis that practice of high level task would make the task low-level, yet the trend in the data leads to the above conclusion. As can be inferred from Figures 2.2, 2.4 and 2.8, there was constant improvement in performance of both right and left hand tapping from trial one to trial four. Moreover, diminishing F values over the trials suggest such improvement was asymmetrically tilted in favor of right hand. (4) Sex differences turned out to be nonsignificant in all the experiments. (5) As the difficulty level of task conditions was increased, there was corresponding disruption in right and left hand tapping (Experiments 1A & 1B).

General Discussion

The results of the four experiments support the postulation of generalized and specialized processors. In Experiment 1A, lateralized interference was observed in the tapping performance of right hand as the task difficulty of motor sequence was increased from D2 - D5. The presence of lateralized interference suggests the possibility that at high level tasks under conditions D3 - D5, rule based processing was carried out by LH processors. Convergent validity for existence of such computation on specialized processors were also obtained in Experiment 2B, where it was observed that, on a different kind of task, only controlled verbal production produced hemispheric asymmetry.

Furthermore, existence of generalized processor was also substantiated by the results of the experiments. In Experiment 1A, under D2 condition (low-level task) generalized interference

as observed, so was it in Experiment 2B with a different kind of nput. These generalized interferences suggest that at low level f task difficulty both hemispheres have processing capabilities. ut results of Experiment 1B were contrary to the postulation of generalized processor' because at task condition D2 lateralized nterference was observed which is against the a priori redictions of the proposed model. The proposed model would have redicted for such situation an increase in the generalized nterference for both hands with addition of a new low level task o an already existing low level task. As noted under the iscussion of Experiment 1B, such results were quite weak to efute the postulation of 'generalized processor' for the ollowing reasons: (i) Though there was a significant disruption the tapping performance of right hand as compared to left hand ith the introduction of requirement of articulation of tapping equences on D2 condition, no significant improvement was visible nder D2 task condition on the next three trials. This is like what happened under the D3 - D5 conditions in the same periment or in Experiment 1A. This suggests the possibility of me other unknown mechanism operating on this sequence which ght have produced the observed asymmetry. (ii) There could be a ssibility that the limited capacity of the generalized processor being fully utilized by the low level task of D2 sequence. The dition of a new low level task i.e. articulation of letters of tor sequence should therefore be carried out by the specialized ocessors of LH thus leading to observed lateralized terference. Moreover, introduction of requirement of rticulation of tapping sequences (consisting of letters) did not

change the lateralization pattern in Experiment 1B, unlike what happened in Experiment 2B with the introduction of a verbal production task with requirement of comprehension (refer Figures 2.4 and 2.8). This also suggests that observed lateralization effect in Experiment 1B under task condition D2, did not refute the postulation of generalized processor. Yet, this result suggests that it would be better to postulate a precise mechanism of resource limitation in the model to account for such results.

The other prediction of the model, that practice of high-level task would make the task a low-level task, stands unsubstantiated because in Experiments 1A, 1B and 2B, lateralized interference was present in the performance of right hand even in the fourth. At the same time, the trend observed in the data suggest the possibility of practice effect as predicted by the model. The results of all the experiments show gradual improvement in tapping performance of right and left hands over trials, but improvement in right hand is faster then the left hand which is evident from the diminishing F values over trials (refer Table 2.3, 2.6 and 2.12 and Figure 2.2, 2.4, 2.6 and 2.8). This suggests that owing to insufficient number of trials used in the experiments, prediction of the model concerning effect of practice remains unsubstantiated. But at the same time, the trend in the data suggests that the hypothesis related to practice effect in the model is correct. One thing, which is pertinent to point out is that fatigue during experimental session might be countering the effect of practice. Thus in future, researchers must use sufficient number of trials to observe the effect of practice. Moreover, they should distribute trials in different sessions to

avoid the effect of fatigue.

The effect of task difficulty of concurrent sequences showed corresponding disruption in right and left hand tapping. The rate of right hand tapping disruption was more then the left hand tapping disruption, suggesting the presence of lateralized interference. But what was intriguing was the increase in generalized interference of left hand with increased task difficulty given that memory for all the sequences was perfect, regardless of the size of motor sequence. It seems that complex motor sequences are made up of two components: a complex motor activity component (peripheral) and a motor program component (central). The observed lateralization effect is due to the second component whereas increase in left hand generalized interference with increasing task difficulty of motor sequence could be attributed to increasingly complex motor activity per se.

Some recent experimental evidence is in line with the findings of the present experiments, thus corroborating the experimental results as well as the proposed model. Wiegersma & Wijnmaalen (1991) reported that lateralized interference in the right hand tapping was observed for controlled verbal production but no such interference existed for habitual verbal production. This finding may also be interpreted on the basis of the model presented here. Since controlled verbal production is a high level task as it requires active attention and programmed activity, lateralized interference was observed. Conversely, habitual verbal production is a low-level task, therefore, no lateralized interference was observed. As a matter of fact, they also observed generalized interference on low level task. Thus,

their finding substantiates the predictions of the proposed model.

Post hoc, analysis of some experimental results also supports the proposed model. For example, as an exception to findings that RH is a superior processor at low exposure duration (e.g., Rizzolatti and Butchel, 1977), low luminance (Hellige & Webster, 1981) etc., Gill and McKeever (1974) found a robust REF-LH advantage in the identification of briefly flashed familiar words. Though results of this experiment were problematic for spatial frequency hypothesis, but not for the present model. Though the data limitation of presented visual stimuli in Gill and McKeever's experiment could have made it unsuitable for programmed processing, yet the familiarity of words counteracted on the data limition. Such data limitation effect may be inferred from Figure 1.1. Therefore a rule based processing is very much possible.

Conclusions

On the basis of aforementioned results and discussion, it is concluded that the left hemisphere specialized processors carry out their processing on high-level task on the basis of rule based computations. Conversely, right hand specialized processors do there computation on high level tasks in a relatively unprogrammed manner. The generalized processor does computation on low-level task under normal input conditions. If input task demand exceeds the capacity limitation of the generalized processor, then the specialized processors, may be pressed into service, as observed in Experiment 1B. Moreover, familiarity/practice of a high-level task would make the task a low-level task as can be seen from the trend in the data in all the experiments.

Limitations

The present work has certain apparent limitations. These are as follow:

(i) The proposed model is tested only in concurrent task paradigm. Therefore, its validity is restricted by all those parameters which limit the validity of concurrent task paradigm. Though a concerted effort was made to overcome the problems which are associated with concurrent task paradigm, still it would be better if the model has convergent validity of other techniques also.

(ii) Two unrelated tasks, i.e., motor tasks of different difficulty levels and verbal production task with and without requirement of comprehension have shown lateralized and generalized interference. It would be better if many more variety of input-tasks show such results.

(iii)Amount of practice trials included in the present experiments was quite inadequate for the purpose of testing the prediction of the model pertaining to the effect of practice.But as already noted, this project had to be completed within a stipulated time frame, therefore, it was practically not feasible to include the ideal number of trials. Similarly, analysis of error data in Experiments 1A and 1B would have increased the reliability of the results. Future studies may be carried out with this orientation.

(iv) The postulation of rule-based computation and random computation in the LH and RH respectively has been done at macro-level i.e. it is suggested that regardless of the nature of specialized processors attributed to LH (e.g., categorical computation, or higher spatial frequency), the net interactive and

dynamic computation in LH would be rule based. But, at the same time the present research is unable to identify any additional specialized processors of LH or RH. Moreover, the proposed relation in the model is descriptive and a quantitative formulation remains a dream to be fulfilled. A number of things are not clear from the model: At what level of task difficulty would the generalized processor transfer the processing task to specialized processors? At what level of data limitation would a low level task become high level task?

Implications

Critical analysis of experimental results and the proposed model suggest that the present work has some important theoretical and methodological implications. More research is needed to verify or falsify some of the predictions of the model. Future research should use different techniques available to study hemispheric asymmetry. It should also use different types and sets of input tasks. Moreover, results have also demonstrated the need for an in depth analysis of different tasks into their subcomponents to rule out the possibility of alternative explanation and to guide the future research in a right direction in a more fruitful way.

Future research may be conducted to crystallize the notion of resource limitation in the context of the present model to account for observed lateralization on a low level task in LH when another low-level task is being handled by the generalized processor as in the case of Experiment 1B. Similarly, use of successive version of concurrent task paradigm needs more

attention as it would be very handy in using tasks of multiple difficulty level. Need is also felt for a statistical technique which could disentangle the counteracting effect of the variablepractice and fatigue by use of some mathematical/statistical tool. For example, performance on low level tasks should be expected to remain unchanged, or deteriorate due to the effect of fatigue. It should not be expected to improve as a result of practice. A high level task performance on the other hand, might or might not show improvement due to practice but it would show deterioration due to effect of fatigue. In principle, it should be possible to use information on low level task performance deterioration to ferret pure practice effect.

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Appendix 1(A1)

Mean Taps/Second and for Baseline (1) and Concurrent Task Conditions (2-5) for Males and Females (Experiment 1A)

Conditions		Males		Females	
		Right Hand	Left Hand	Right Hand	Left Hand
1.	Mead	6.16	5.40	6.01	5.23
2.	Mean	4.48	3.91	4.42	3.76
3.	Mean	3.17	3.07	3.10	2.98
4.	Mean	3.02	2.84	3.03	3.10
5.	Mean	2.58	2.48	2.49	2.57

Abbreviation: Condition 1 = Baseline (D1); Conditions 2-5 = Concurrent Condition with Increasing Difficulty(D2 - D5).

Appendix 1(2A)

Mean Taps/Second for Baseline (1)andConcurrent Conditions (2-5) for Males and Females (Experiment 1B)

Conditions		Males		Females	
		Right Hand	Left Hand	Right Hand	Left Hand
1.	Mead	5.65 (5.15)	4.80 (4.36)	5.78 (5.40)	5.19 (4.51)
2.	Mean	4.57 (3.83)	3.69 (3.60)	4.42 (3.83)	3.95 (3.54)
3.	Mean	2.72 (3.33)	2.92 (3.21)	3.21 (3.37)	3.12 (3.10)
4.	Mean	3.09 (3.07)	2.63 (3.22)	2.77 (2.92)	2.57 (3.04)
5.	Mean	2.00 (2.39)	2.17 (2.28)	2.26 (2.61)	2.30 (2.45)

Abbreviation: Condition 1 = Baseline (D1)
Conditions(2-5) = Concurrent Conditions with Increasing Difficulty (D2 - D5)

Mean Outside Parantheses is for OneTrial Without Verbalization of Tapping Sequence.

Mean Inside Parantheses is for Three Trials With Verbalization of Tapping Sequence.

Appendix 1(A3)

Mean Taps/Second for Base line (1) in Concurrent Task Condition (2) for Males and Females (Experiment 2A)

Conditions	Males		Females	
	Right Hand	Left Hand	Right Hand	Left Hand
. Mean	5.58	4.60	5.38	4.42
. Mean	5.19	4.38	5.14	5.27

Appendix 1(A4)

Mean Taps/Second for Base line (1) in Concurrent Task Condition (2) for Males and Females (Experiment 2A)

Conditions	Males		Females	
	Right Hand	Left Hand	Right Hand	Left Hand
. Mean	5.98 (5.73)	5.10 (5.08)	5.73 (5.54)	4.79 (4.77)
. Mean	5.52 (4.75)	4.85 (4.43)	5.17 (4.49)	4.49 (3.97)

Value inside the Paranthesesis with Requirement of Comprehension.

Appendix 2

Summary of ANOVA for Tapping Data (Experiment 1A)

Source	SS	df	MS	F
1. Between subject	241.87	19	12.73	
2. A (Sex)	0.68	1	0.68	0.05
3. Subject Within Group	241.18	18	13.39	
4. Within subject	1392.15	780	1.78	
5. B (Hand)	16.68	1	16.68	22.23**
6. C (Familiarization)	10.46	3	3.48	7.84
7. D (Task conditions)	1028.09	4	257.012	161.34**
8. A x B	0.45	1	0.453	0.604
9. A x C	0.18	3	0.062	0.008
10. A x D	3.09	4	0.773	0.485
11. B x C	0.17	3	0.05	0.33
12. B x D	18.41	4	4.60	13.44**
13. C x D	25.21	12	2.10	7.21**
14. A x B X C	0.02	3	0.06	0.18
15. A x B x D	0.54	4	0.13	0.79
16. A x C X D	3.02	12	0.25	0.86
17. B x C x D	3.49	12	0.29	2.07
18. A x B x C x D	2.27	12	0.18	1.32
19. B x Sub.W.Group	13.51	18	0.75	
20. C x Sub.W.Group	24.00	54	0.44	
21. D x Sub.W.Group	114.70	72	1.59	
22. B x C Sub.W.Group	9.40	54	0.17	
23. B x D Sub.W.Group	24.64	72	0.34	
24. C x D Sub.W.Group	62.87	216	0.29	
25. B x C x D Sub.W.Group	30.40	216	0.12	
Total	1634.03	799	2.04	

** = P < .01

Appendix 3

Summary of ANOVA for Tapping Data (Experiment 1B)

	Source	SS	df	MS	F
1.	Between subject	187.39	19	9.86	
2.	A (Sex)	0.63	1	0.63	0.06
3.	Subject within group	186.77	18	10.37	
4.	Within subject	888.77	780	1.13	
5.	B (Hand)	14.47	1	14.47	46.60**
6.	C (Familiarization)	0.50	3	0.16	0.86
7.	D (Task conditions)	628.43	4	157.11	119.23**
8.	A × B	0.07	1	0.07	0.21
9.	A × C	.617	3	0.20	0.05
10.	A × D	3.95	4	0.98	0.75
11.	B × C	0.33	3	0.11	1.41
12.	B × D	17.65	4	4.41	21.83**
13.	C × D	21.00	12	1.75	8.28**
14.	A × B × C	0.58	3	0.19	2.47
15.	A × B × D	0.37	4	0.09	0.46
16.	A × C × D	1.20	12	0.10	0.47
17.	B × C × D	3.20	12	0.35	4.16**
18.	A × B × C × D	0.80	12	0.06	0.79
19.	B × Sub.W.Group	5.58	18	0.31	
20.	C × Sub.W.Group	10.49	54	0.19	
21.	D × Sub.W.Group	94.87	72	1.31	
22.	B × C Sub.W.Group	4.26	54	0.07	
23.	B × D Sub.W.Group	14.55	72	0.20	
24.	C × D Sub.W.Group	45.92	216	0.21	
25.	B × C × D Sub.W.Group	18.15	216	0.08	
Total		1075.48	799	1.34	

** = P < .01

Appendix 4

Summary of ANOVA for Tapping Data (Experiment 1A)

	Source	SS	df	MS	F
1.	Between subject	75.57	19	3.97	
2.	A (Sex)	1.43	1	1.43	0.34
3.	Subject within group	74.13	18	4.11	
4.	Within subject	90.31	300	0.30	
5.	B (Hand)	65.63	1	65.63	130.14
6.	C (Familiarization)	0.08	3	0.03	0.88
7.	D (Task conditions)	4.91	1	4.91	19.77**
8.	A × B	0.02	1	0.02	0.02
9.	A × C	0.15	3	0.04	0.08
10.	A × D	0.25	1	0.25	1.08
11.	B × C	0.01	3	0.01	0.23
12.	B × D	0.27	1	0.27	7.45
13.	C × D	0.99	3	0.33	33.10**
14.	A × B × C	0.007	3	0.002	0.15
15.	A × B × D	0.02	1	0.02	0.67
16.	A × C × D	0.03	3	0.01	1.15
17.	B × C × D	0.03	3	0.01	1.15
18.	A × B × C × D	0.03	3	0.01	1.08
19.	B × Sub.W.Group	9.07	18	0.50	
20.	C × Sub.W.Group	1.69	54	0.031	
21.	D × Sub.W.Group	4.47	18	0.24	
22.	B × C Sub.W.Group	0.84	54	0.01	
23.	B × D Sub.W.Group	0.65	18	0.03	
24.	C × D Sub.W.Group	0.54	54	0.01	
25.	B × C × D Sub.W.Group	0.49	54	0.009	
Total		165.88	319	0.52	

** = $P < .01$

Appendix 5

Summary of ANOVA for Tapping Data (Experiment 2B)

	Source	SS	df	MS	F
1.	Between subject	101.78	19	5.35	
2.	A (Sex)	7.47	1	7.47	1.42
3.	Subject within group	94.31	18	5.23	
4.	Within subject	108.04	300	0.36	
5.	B (Hand)	0.39	1	31.19	168.06**
6.	C (Familiarization)	7.89	3	2.63	56.85**
7.	D (Task conditions)	44.07	1	44.07	128.93**
8.	A × B	0.28	1	0.28	1.54
9.	A × C	0.01	3	0.03	0.08
10.	A × D	0.16	1	0.16	0.49
11.	B × C	0.76	3	0.25	14.32
12.	B × D	1.38	1	1.38	19.04**
13.	C × D	4.18	3	1.39	30.55
14.	A × B × C	0.09	3	0.03	1.97
15.	A × B × D	0.02	1	0.02	0.38
16.	A × C × D	0.01	3	0.04	0.09
17.	B × C × D	0.08	3	0.02	1.43
18.	A × B × C × D	0.05	3	0.01	0.87
19.	B × Sub.W.Group	3.34	18	0.18	
20.	C × Sub.W.Group	2.50	54	0.04	
21.	D × Sub.W.Group	6.15	18	0.34	
22.	B × C Sub.W.Group	0.95	54	0.01	
23.	B × D Sub.W.Group	1.31	18	0.07	
24.	C × D Sub.W.Group	2.46	54	0.04	
25.	B × C × D Sub.W.Group	1.05	54	0.01	
Total		209.82	319	0.65	

** = P < .01

Appendix 3(A)

Summary of Simple-Simple Effects and Interaction effects analysis for Tapping Data (Experiment 1B)

Source	SS	df	MS	F
B at CD11	5.18	1	-	12.24**
B at CD21	8.10	1	-	19.14**
B at CD31	6.97	1	-	16.47**
B at CD41	6.08	1	-	14.37**
B at CD12	4.55	1	-	10.75**
B at CD22	1.08	1	-	2.25
B at CD32	0.49	1	-	1.04
B at CD42	0.52	1	-	1.22
B at CD13	0.03	1	-	0.07
B at CD23	0.75	1	-	1.75
B at CD33	0.29	1	-	0.56
B at CD43	0.14	1	-	0.33
B at CD14	1.08	1	-	2.25
B at CD24	0.40	1	-	0.94
B at CD34	0.34	1	-	0.80
B at CD44	0.00	1	-	0.00
B at CD15	0.12	1	-	0.28
B at CD25	0.52	1	-	1.22
B at CD35	0.07	1	-	0.16
B at CD45	0.04	1	-	0.01
	ERROR TERM 0.423			
C at BD11	2.99	3	0.99	3.09**
C at BD12	6.70	3	2.23	6.94**
C at BD13	2.30	3	0.76	2.38
C at BD14	0.40	3	0.13	0.41
C at BD15	2.07	3	0.69	2.10
C at BD21	4.68	3	1.56	4.80**
C at BD22	1.02	3	0.34	1.05
C at BD23	1.02	3	0.34	1.05
C at BD24	4.18	3	1.39	4.33**
C at BD25	0.58	3	0.19	0.60
	ERROR TERM 0.321			
D at BC11	165.82	4	41.45	67.24**
D at BC12	94.80	4	23.70	38.44**
D at BC13	93.61	4	23.40	37.45**
D at BC14	83.02	4	20.75	33.66**
D at BC21	96.80	4	24.20	39.21**
D at BC22	49.05	4	12.26	19.86**
D at BC23	45.76	4	11.44	18.55**
D at BC24	42.66	4	10.66	15.04**
	ERROR TERM 0.616			

Source	SS	df	MS	F
BC at D1	0.25	4	0.062	0.35
BC at D2	1.29	4	0.32	1.85
BC at D3	0.59	4	0.14	0.77
BC at D4	1.69	4	0.42	2.42
BC at D5	0.57	4	0.14	0.81
	ERROR TERM 0.174			
BD at C1	6.03	3	2.01	5.87**
BD at C2	6.28	3	0.15	6.12**
BD at C3	5.57	3	1.85	5.42**
BD at C4	4.27	3	1.42	4.16**
	ERROR TERM 0.342			
CD at B1	14.72	1	-	50.50**
CD at B2	10.76	1	-	36.97**
	ERROR TERM 0.291			
B at D1	26.06	1	-	61.60**
B at D2	5.23	1	-	12.36**
B at D3	0.62	1	-	1.46
B at D4	0.01	1	-	0.03
B at D5	0.19	1	-	0.45
	ERROR TERM 0.423			
D at B1	122.55	4	30.63	56.06**
D at B2	223.54	4	55.88	102.25**
	ERROR TERM 0.546			
C at D1	7.53	3	2.51	7.79**
C at D2	6.43	3	2.14	6.60**
C at D3	2.77	3	0.92	2.86
C at D4	2.77	3	0.92	2.86
C at D5	2.08	3	0.69	2.15
	ERROR TERM 0.321			
D at C1	256.61	4	64.15	104.05**
D at C2	137.58	4	34.39	55.97**
D at C3	133.80	4	33.45	54.25**
D at C4	121.43	4	30.35	49.24**
	ERROR TERM 0.321			

Abbreviation: ** = $p < 0.01$; * = $p < 0.05$
A = Sex B = Hand
C = Practice Trials D = Task Conditions

Appendix 2(A)

Summary of Simple-Simple Effect Analysis for Tapping Data (Experiment 1A)

Source		SS	df	MS	F
Within Subject		23.74	1	-	56.12
1.	Between B at D1				
2.	B at D2	8.36	1	-	19.76**
3.	B at D3	0.48	1	-	1.13
4.	B at D4	0.12	1	-	0.28
5.	B at D5	0.00	1	-	0.00
	ERROR TERM		0.432		
6.	Between D at B1	657.72	4	164.43	301.15**
7.	D at B2	388.73	4	97.18	177.98**
	ERROR TERM		0.546		
8.	Between C at D1	2.98	3	0.99	3.08
9.	C at D2	6.31	3	2.10	6.53**
10.	C at D3	8.52	3	2.84	8.82**
11.	C at D4	10.24	3	3.41	10.60**
12.	C at D5	7.63	3	2.54	7.90**
	ERROR TERM		0.321		
13.	Between D at C1	219.27	4	54.81	88.98**
14.	D at C2	240.13	4	60.03	97.45**
15.	D at C3	217.29	4	54.32	88.18**
16.	D at C4	230.80	4	57.70	93.66**
	ERROR TERM		0.616		

Abbreviation:
- ** = $p < 0.01$
- * = $p < 0.05$
- A = Sex
- B = Hand
- C = Practice Trials
- D = Task Conditions

Appendix 4(A)

Summary of Simple-Simple Effect Analysis for Tapping Data (Experiment 2A)

	Source	SS	df	MS	F
	Within Subjects				
1.	C at D1	0.43	3	0.14	21.50**
2.	C at D2	0.64	3	0.21	32.00**
		ERROR TERM 0.02			
3.	D at C1	3.33	1	-	49.91**
4.	D at C2	1.66	1	-	23.88**
5.	D at C3	0.65	1	-	9.35**
6.	D at C4	0.25	1	-	3.59
		ERROR TERM 0.02			
7.	B at D1	37.11	1	-	137.49**
8.	B at D2	9.71	1	-	35.96**
		ERROR TERM 0.27			
9.	D at B1	3.73	1	-	26.26**
10.	D at B2	1.45	1	-	10.21**
		ERROR TERM 0.14			

** = $p<0.01$.

Appendix 5(A)

Summary of Simple-Simple Effects for Tapping Data (Experiment 2B)

Source	SS	df	MS	F
Within subject				
1. B at D1	22.86	1	-	176.52**
2. B at D2	9.71	1	-	74.98**
ERROR TERM 0.12				
3. D at B1	30.54	1	-	147.18**
4. D at B2	14.92	1	-	71.90**
ERROR TERM 0.20				
5. C at D1	0.89	3	0.28	18.26**
6. C at D2	11.24	3	3.74	244.34**
ERROR TERM 0.04				
7. D at C1	3.05	1	-	25.41**
8. D at C2	21.11	1	-	175.91**
9. D at C3	13.06	1	-	108.83**
10. D at C4	11.03	1	-	91.91**
ERROR TERM 0.12				
11. B at C1	12.48	1	-	208.00**
12. B at C2	13.77	1	-	229.50**
13. B at C3	5.83	1	-	97.16**
14. B at C4	6.10	1	-	101.66**
ERROR TERM 0.06				
15. C at B1	6.73	3	2.24	210.31**
16. C at B2	1.92	3	0.64	60.00**
ERROR TERM 0.12				

Abbreviation:
- ** = $P < 0.01$
- * = $p < 0.05$
- A = Sex
- B = Hand
- C = Practice Trials
- D = Task Conditions

Appendix 6

The value of philosophy is, in fact, to be sought largely in its very uncertainy. The man who has no trace of philosophy goes through life imprisioned in the prejudices derived from commonsense, from the habitual beliefs of his own age or his nation, and from convictions which have grown up in his mind without the cooperation or consent of his deliberate reason. To such a man the world becomes definite, finite, obvious; common objects rouse no question and unfamiliar possibilities are conteptously rejected. As soon as we begin to philosophise, on the contrary, we find that even the most everyday things lead to problem to which very incomplete answers can be given. Philosophy, though unable to tell us with certainty what the true answers are to the doubts it raises, is able to suggest many possibilities which in large our thoughts and free them from the tyranny of custom. Thus, while diminishing our feeling of certainty as to what things are, it greatly increases our knowledge as what they may be. It removes the stupid dogmatism of those who have never troubled into the region of liberating doubt, and it keeps alive our sense of wonder by showing things in an unfamiliar aspect.